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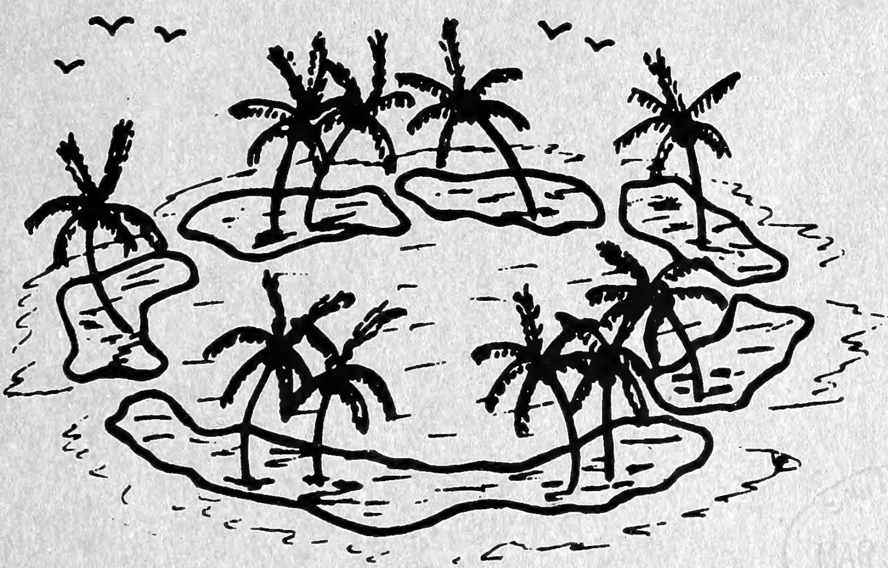
December 31, 1972

ATOLL RESEARCH BULLETIN



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ATOLL RESEARCH BULLETIN

No. 151

BACTERIAL COUNTS IN SURFACE OPEN WATERS OF ENIWETOK ATOLL, MARSHALL ISLANDS

by Louis H. DiSalvo

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BACTERIAL COUNTS IN SURFACE OPEN WATERS OF ENIWETOK ATOLL, MARSHALL ISLANDS

by Louis H. DiSalvo[1]

INTRODUCTION AND METHODS

During my investigations of coral reef microbiology at Eniwetok Atoll, Marshall Islands in 1968, large numbers of bacteria were found inhabiting coral reef internal sediments (10^7-10^8 colonies/g; DiSalvo, 1969). With the high level of metazoan activity on reefs it was expected that sediment processing and disturbance might cause the release of bacteria, contributing to the organic particulate enrichment of lagoon waters (Marshall, 1965; Johannes, 1967). To my knowledge, no bacteriological data were available which compared oceanic counts to lagoonal counts near an atoll, and therefore the following measurements were made both in reference to the work at hand and as a general contribution to atoll ecology.

Open water sampling for aerobic heterotrophic bacteria was carried out on six bi-weekly dates in June and July 1968. A total of 24 samples of surface seawater were obtained at oceanic and lagoonal stations. In addition, a total of 14 samples were obtained downstream from the Japtan reef at the surface and at 2 meters depth. Sample locations are shown in Figure 1. Surface (top 5 cm) water samples were obtained in sterile 200 ml prescription bottles from a boat. Skin diving was employed to obtain the 2 m samples. Samples were kept on ice for return to the laboratory, and plated for bacterial counts within five hours of collection. The plating medium was ZoBell 2216e (Oppenheimer and ZoBell, 1952) solidified with 1.5% (w/v) agar. Duplicate pour plates were made using 0.1 ml raw seawater inocula and 10 ml medium which had been cooled to 40-45°C. Plates were incubated at ambient temperature (30°C) for 48 hours and then counted for total colonies.

RESULTS AND DISCUSSION

Bacterial counts for numbered samples located by Figure 1 are listed in Table 1. These counts are within order of magnitude limits established by other investigators using similar methods on waters near non-atoll reefs (Table 3). Table 2 lists counts for two depths immediately behind the Japtan Reef. Summarized results in Table 3 suggest there was no significant difference between oceanic and back-reef counts.

Conclusions from these data are tentative and preliminary. Comparisons with plate counts of other workers in Table 3 have been made for convenience, although they may be invalidated by slight differences in methodology and materials. The limitations of the plate count technique in obtaining "true counts" are well known (ZoBell, 1946; Jones and Jannasch, 1959) and present results can only be considered as a measure of relative microbial activity. The counts are

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within higher ranges expected for clear tropical pelagic waters, and it may therefore be hypothesized that the waters surrounding the atoll are enriched in some way, perhaps by local upwelling or organic enrichment from the reefs.

The small numbers of sample platings preclude rigorous statistical interpretations of the data. More seriously, I was unable to sample the same water mass flowing from ocean to lagoon over the Japtan Reef for the before-after measurements. Both these factors were the result of logistical problems, helping to explain why there are essentially no microbiological data available for atoll waters. Since it has previously been suggested that the Japtan Reef was in a steady state with regard to the import and export of matter and energy (Odum and Odum, 1965), it is not unreasonable to deduce from the available data that this reef is in equilibrium with regard to input and output of heterotrophic bacteria.

Future studies should attempt to confirm present results under various seasonal and tidal regimes, and extend the measurements to representative depths within and outside the atoll. Such measurements might be useful in studies of outer slope upwelling and local enrichment due to the coral reefs.

ACKNOWLEDGEMENT

The author wishes to thank the Eniwetok Marine Biological Laboratory and the University of Hawaii for support and facilities used to accomplish this research.

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Table 1. BACTERIAL COUNTS FOR ENIWETOK ATOLL OPEN WATERS

Date 1968	Sample* #	Colonies/ml**	Date 1968	Sample #	Colonies/ml
6/16	1	780	6/23	13	70
"	2	720	"	16	140
"	3	40	"	18	50
"	4	600	"	21	80
"	5	130	"	24	160
"	9	100	6/30	12	180
"	15	800	"	14	100
6/23	6	100	"	17	500
"	7	60	"	19	50
"	8	130	"	20	100
"	10	30	"	22	150
"	11	130	"	23	30

*For sample location, see Fig. 1.
**Colonies/ 0.1 ml plated x 10.

Table 2. BACTERIAL COLONY COUNTS FOR JAPTAN I. BACK-REEF WATERS*

Date	Surface samples		Samples from 2m depth**	
1968	Sample #	Colonies/ml	Sample #	Colonies/ml
7/15	1	150	1d	250
	2	250	2d	500
	-	-	3d	350
7/17	3	50	4d	160
	4	330	5d	150
	5	550	-	-
7/19	6	80	6d	300
	-	-	7d	330
	-	-	8d	250
Mean values		235		$\cong$ 285

* Water depth approximately 4 meters.
** Obtained by diving.

Table 3. SUMMARY OF COLONY COUNTS FOR ENIWETOK ATOLL OPEN WATERS

Stations	Number of samples	Colonies/ml
Ocean (nos. 1-5, 7-11	10	272 ± 100
Lagoon (all Japtan*, nos. 20-24)	19	222 ± 10
Previous data, near reefs		
Gee (1932)[1]	3	100,150,700**
Sisler (1962)[2]	nd	< 10-10^3
Gundersen and Stroupe (1967)[3]	(a) 5	50,60,1360,12,42**
	(b) 3	13,2,5**
Sieburth (unpub.)[4]	4	215,235,250,700**

*See table 2.

**Individual results.

[1] Open water near Florida reef tract (Gulf Stream, Bird Key Harbor, Marquesas lagoon).

[2] Water over Great Bahama Bank west of Andros I.

[3] (a) immediately outside northern Kaneohe Bay, Hawaii.
(b) Kauai I., Hawaii, 1.5-2.5 miles offshore.

[4] unpolluted lagoon stations, Majuro Atoll, Marshall Is., Feb-Apr. 1970. Unpub. data of J.McN.Sieburth, U.Rhode I. Narragansett Marine Laboratory, Kingston.

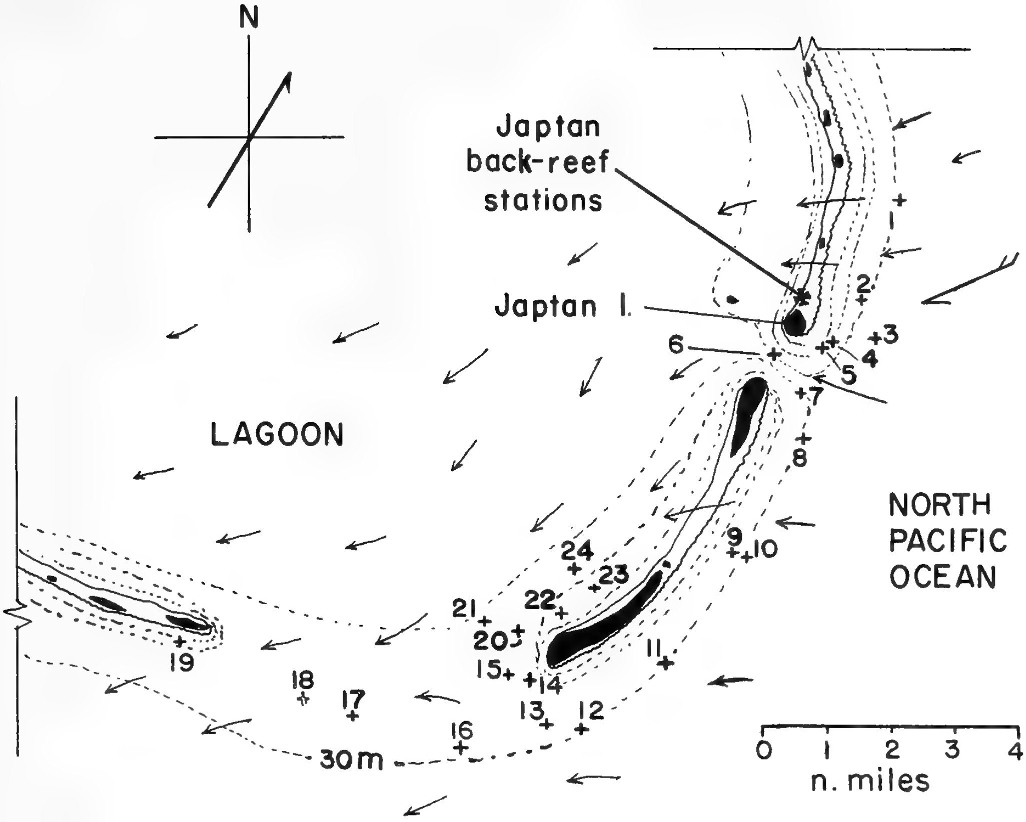

Figure 1. Southeast quadrant of Eniwetok Atoll, Marshall Is. (11°30'N, 165°15'W), to show sampling stations. Approximate current pattern is designated by small arrows. Contour interval 10 meters.

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MARINE STUDIES ON THE NORTH COAST OF JAMAICA

edited by Gerald J. Bakus

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MARINE STUDIES ON THE NORTH COAST OF JAMAICA

Edited by Gerald J. Bakus[1]

INTRODUCTION

During July and August of 1970 a group of 12 students and several instructors participated in research and teaching in the second Organization for Tropical Studies (OTS) course in Tropical Marine Biology. The primary site was the Discovery Bay Marine Laboratory and immediate environs on the north coast of Jamaica. The laboratory provided facilities for maintaining live marine organisms, under the direction of Mr. Norman Copland, Manager.

Discovery Bay consists of a variety of marine communities, particularly sandy bottoms, *Thalassia* beds, and coral patch reefs. Among the most striking communities is an exceptional sponge bed located at a depth of 50-75 feet (15-23 m) just off Colombus Park, with certain specimens approaching the size of a washtub. The bay is contained by a reef crest of zoanthids, scleractinian corals, sea urchins, and numerous associated organisms. Beyong the reef crest, scleractinian corals slope gently seaward before the island shelf plunges into the depths. Underwater visibility on the outside of the reef crest often approaches 150 feet (46 m). Scleractinian corals are magnificently developed along this narrow shelf. Sclerosponges occur as cavernicolous cryptofauna in waters 8 to 92 meters deep (Hartman and Goreau, 1970). Goreau (1959) presented a detailed report on the ecology of coral reefs on the north coast of Jamaica. The low incidence of exposed soft-bodied invertebrates and the low standing crops of exposed fleshy algae on the reef slope are in part interpreted as the evolutionary product of tropical predator-prey and grazer-plant interactions (Bakus, 1969).

The abstracts presented below summarize studies conducted during the OTS program. A complete report of our research activities is on file in the OTS North American Office.

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[1]Allan Hancock Foundation, University of Southern California, Los Angeles, California

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ABSTRACTS

Distributional patterns of rocky intertidal gastropods in Discovery Bay, Jamaica

By Lenora H. Atsatt, Dept. of Environmental and Population Biology, Univ. of California, Irvine

Distributional patterns of rocky intertidal gastropods in Discovery Bay, Jamaica, were examined in an attempt to develop a quantitative method of describing habitat differentiation. The relationship of common species of gastropods of the families Neritidae and Littorinidae to a series of physical variables, including texture, moisture content, slope angle, exposure, and zonation was analyzed using chi-square tests. Each species was found to differ in habitat preference from the other species for at least one of these variables. *Tectarius muricatus*, a littorine, was distinct from all other species in habit preference, while the three *Nerita* spp. were less clearly segregated. *Littorina ziczac* and *Echininus nodulosus*, two littorines which were relatively unsegregated with regard to the physical variables, were found to be positively associated.

Activity patterns in *Tectarius muricatus* were examined in an attempt to relate behavioral response to distributional patterns. Results indicated that moisture level is the most critical factor involved for the initiation and termination of activity, and that combinations of other environmental stimuli are responsible for direction of motion.

Model experiments on the releasing mechanism of cleaning behavior in the shrimp Periclimenes pedersoni

By Patrick L. Colin, School of Marine and Atmospheric Sciences, Univ. of Miami, Miami, Florida

Periclimenes pedersoni exhibits cleaning behavior towards anesthetized fish, paper fish models, paper fish shapes, and paper rectangles. When satiated with food the shrimp did not exhibit any cleaning behavior towards any of the models. Food deprivation for periods greater than 24 hours lowered the selectivity of the cleaning response to models. A white paper model with inked features produced cleaning responses most often; more often than an anesthetized cardinal fish, *Apogon maculatus*. Contrast between ground color and markings was most important in releasing cleaning behavior. Movement of the model inhibited release of cleaning, and olfactory clues were not important.

Some observations on the metabolism and growth of Thalassia testudinum König and its epibiota

By David D. Dow, Dept. of Zoology, Univ. of Georgia, Athens

On the basis of bottom area, *Thalassia* plants were found to have a metabolic rate of 3.47 g $0_2/m^2$ per day. On the basis of leaf area the *Thalassia* blades with epibiota had a metabolic rate of 2.27 g $0_2/m^2$ per day, while the epibiota alone accounted for 0.18 g $0_2/m^2$ per day. Exclosure experiments suggested that grazing by reef fishes and invertebrates does significantly affect the standing crop of *Thalassia* but not the blade length distribution.

The distribution and abundance of anemones and their commensal shrimp in Discovery Bay, Jamaica

By Catherine P. Engel, Dept. of Biological Sciences, Univ. of California, Santa Barbara

A two-week study of the distribution and abundance of the anemones and their associated shrimps was done in Discovery Bay, Jamaica. Transect surveys were made in mixed *Thalassia* (10 ft. depth), a shallow inshore shelf (1-2 ft. depth), the reef crest (1-2 ft. depth), and the back reef (2-3 ft. depth), with twenty-four 2 m^2 samples in each area. The anemones that were surveyed included *Bartholomea annulata, Stoichactis helianthis, Condylactis gigantea, Heteractis lucida, Lebrunia coralligens,* and a burrowing anemone (unidentified). The anemone species were most evenly ranked in the mixed *Thalassia* and the mean number of anemones per 2 m^2 was greatest in the reef crest sample. No shrimps were associated with *Heteractis, Lebrunia,* or the burrowing anemone. *Periclimenes yucatanicus* and *Periclimenes pedersoni* were found on *Bartholomea* and *Condylactis*. *Periclimenes* sp. was found only on *Stoichactis*. *Alpheus armatus* was associated with *Bartholomea*. *Thor* sp. was found with *Stoichactis* and *Bartholomea*. *Thor amboinensis* was associated with *Bartholomea, Condylactis,* and *Stoichactis*. *Heteromysis actiniae* was found with *Bartholomea*. The greatest number of shrimp species present was in the mixed *Thalassia* area.

The distribution and abundance of both the anemones and their shrimps were variable from one area to another. This was primarily attributed to substrate and water movement.

Patterns of distribution of Foraminifera on Thalassia testudinum

By Malcolm G. Erskian, Institute of Ecology & Bodega Marine Laboratory, Univ. of California, Davis

In Discovery Bay, Jamaica, the spatial distribution and density of epiphytic Foraminifera was studied. Two species of polythalamous Foraminifera, *Planorbulina* sp. (Family Planorbulinidae) and *Sorites* sp. (Family Soritidae) were found epiphytically on turtle grass, *Thalassia testudinum*. Samples were collected by removing all of the *Thalassia* in an area of 0.1 square meter. Three replicate 0.1 square meter samples were taken at a depth of 3 meters. From each 0.1 m^2 plots, ten whole *Thalassia* plants were chosen and each blade divided into quadrats. The number of each species of Foraminifera was recorded. A coefficient of dispersion (r) was calculated by the variance: mean ratio method. *Planorbulina* sp. and *Sorites* sp. were found to have an aggregated spatial distribution. Variance: mean ratios were found to be significantly greater than unity, except one station. Aggregation seems more pronounced in *Planorbulina* sp., r ranging from 1.4 to 2.4, than *Sorites* sp., with r ranging from 0.9 to 1.4. There seems to be a niche partitioning between species. *Planorbulina* sp. is found along the margins of the *Thalassia* blade in a higher proportion than toward the median, whereas *Sorites* sp. is found in a higher proportion in the median. The epiphytic niche increases the area of available substrate when compared to the sediment surface. *Thalassia* was found to increase the available substrate to Foraminifera by a factor of 6, producing a very high population density when compared to a unit area of sediment surface. *Planorbulina* sp. averaged over 60,000 individuals per square meter sediment surface and *Sorites* sp. over 12,000.

A preliminary study on the toxicity of the sponge Haliclona rubens (Pallas) de Laubenfels

By Gerardo Green-Macial, Dept. of Biological Sciences, Univ. of Southern California, Los Angeles

A high degree of toxicity was found in the sponge *Haliclona rubens*. The toxin was extracted by homogenizing 4 g of live sponge in each of the following solvents: hexane, benzene, ether, chloroform, acetone, ethanol, methanol, and distilled water. After centrifugation and evaporation of the supernatent, the extracts were tested against squirrelfishes *(Holocentrus rufus)*. The behavior of the fish was observed and timed. Control experiments were run each time.

A coefficient of toxicity (α) was calculated according to the following formula: $\alpha = \frac{xt}{y} \times 100$ where: x = weight of the toxin, y = weight of the dead fish, t = time in which death of the fish occurs. The effectiveness of the toxin and its solubility are inversely proportional to the value. In the case of *H. rubens*, the most effective solvent (lowest α value) is acetone (0.28 g of acetone-toxin extract in 2 liters of sea water, killed a 53.2 g fish in 5.5 min.).

Aspects of the biology of the bluehead wrasse Thalassoma bifasciatum

By John B. Heiser, Dept. of Anatomy, Cornell University, Ithaca, New York

Because of its shallow water diurnal habits and non-retiring nature, the labrid genus *Thalassoma* is an appropriate organism for investigation of the morphological and behavioral adaptations that have contributed to the success of the suborder Labroidei in tropical marine shore waters. Pectoral muscular modifications, as well as extensive development of the cephalic lateralis system, correlate with observed behavior patterns. The behavioral contexts of the varied color patterns were tentatively identified and found to be rather consistent. The depth distribution was examined and thought to correlate with the environmental diversity of coralline areas, especially below 10 meters. The species is not uniformly distributed on all reef zones nor is there a uniform decline with depth, though a large percentage of the population is in water less than 30 meters. The species is an opportunistic micro-carnivore, including its cleaning behavior. Despite this latter behavior, it does not enjoy complete immunity from predation. Aggregate spawning by yellow phase fishes was repeatedly observed and analyzed into successive components. Spawning by bluehead phases was not observed but it is felt that such polymorphism may be an important key to the success of the Labroidei, many of whose members show similar patterns.

Observations on the associations and feeding of six species of prosobranch gastropods on Anthozoans

By Alan C. Miller, Dept. of Biology, Univ. of Oregon, Eugene

The associations and predation of prosobranch gastropods on anthozoans was studied in Discovery Bay, Jamaica. *Coralliophila abbreviata* was associated with 12 scleractinian coral species, *Ricordea florida* (Actiniaria), and *Zoanthus sociatus* (Zoanthidea). *Coralliophila caribea* was associated with 6 stony corals, 3 gorgonians, *Zoanthus florida*, and the actiniarians *Rhodactis sanctithomae* and *Ricordea florida*. Two methods of feeding were observed for *Coralliophila*: the proboscis is inserted through the epidermis of corals into the gastrodermis where it is moved around; the proboscis is extended over the colony and inserted into the oral opening of an individual polyp. It could not be discerned what the *Coralliophila* were digesting, but zooxanthellae were found in the digestive tract.

Cyphoma gibbosum is associated with erect gorgonians. The many undigested zooxanthellae in its fecal pellets suggest that it mainly digests animal tissues.

Heliacus cylindricus and *H. infundibuliformis* (one individual each) were found among *Zoanthus florida* polyps. Feeding was not observed.

One *Calliostoma javanicum* (Trochidae) was found, and it consumed part of an *Agaricia agaricites* colony (scleractinian coral) in the laboratory. Its fecal pellets contained many undigested zooxanthellae and undischarged nematocysts which suggests that it might be digesting the animal tissue. This has been observed before at the Discovery Bay Marine Laboratory and is of interest since trochids are considered to be herbivores.

Relationships between type of locomotion, size, and speed in larger gastropod molluscs

By Susanne E. Miller, Dept. of Zoology, Univ. of Washington, Seattle

The speed and methods of locomotion in a wide size range of large Caribbean gastropod species were studied in order to determine the effects of absolute size on different types of locomotion. *Cittarium pica* and *Fasciolaria tulipa* move by retrograde alternate ditaxic waves of muscular contraction of the sole of the foot, *Strombus gigas* by leaping movements, and *Cassis* species apparently by ciliary action. Leaping is the fastest method of locomotion and ciliary movement is slowest in these large gastropods. Absolute speed on suitable horizontal substrates seems to increase with size over the size range of the species tested, and absolute speed on vertical or inclined substrates also increases but at a lower rate. These effects of weight on speed are most apparent in the species with ciliary locomotion and in *Fasciolaria tulipa*, in which adhesion at higher speeds is poor. Speed is inversely proportional to size in *Cittarium pica* but directly proportional to size in *Strombus gigas*. The limitations of the types of locomotion with absolute size are discussed with respect to different types of habitats.

Preliminary study of six Jamaican blue crabs, genus Callinectes (Decapods: Portunidae)

By Elliott A. Norse, Dept. of Biological Sciences, Univ. of Southern California, Los Angeles

Results of a summer study of Jamaican blue crabs are presented. Ecological separation between the six Jamaican species is discussed. Collecting localities for *Callinectes sapidus*, *C. bocourti* and *C. exasperatus* indicate that these prefer mud bottoms to sand bottoms; *C. danae* is found on both bottom types, while *C. marginatus* and *C. ornatus* are members of sandy bottom communities. *Callinectes bocourti* and *C. sapidus* males are found in fresh water rivers; *C. danae*, *C. exasperatus* and *C. sapidus* females live in estuaries and brackish bays while *C. marginatus* and *C. ornatus* are recorded from marine situations. Further separation based on feeding is proposed, with *C. exasperatus* and *C. marginatus* being able to exploit hard-bodied food organisms, while other species are not anatomically equipped to do so. An albinistic population of *Callinectes ornatus* is described in conjunction with implications on the evolutionary role of geographical isolation in speciation. Cannibalism is an important population control in *Callinectes* species. Laboratory studies of interspecific competition found males of *C. exasperatus* occupying the dominant position in shelter hierarchy while males of *C. bocourti* are more active in asserting feeding dominance in a two-species experiment. *Callinectes* species are found to be the largest and most active carnivores resident in estuarine and brackish environments on Jamaica's northern shore. Using a "Number of Features of Difference" table, a tentative phylogeny of six Jamaican and a seventh species of swimming crabs from the Pacific (Panama) is proposed. *Callinectes marginatus* and *C. exasperatus* are found to compose a closely related "species group" while *C. ornatus*, *C. danae* and *C. arcuatus* represent a second species group.

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On the biology of Ophioblennius atlanticus

By Janet Osburn, Dept. of Zoology, Univ. of Washington, Seattle

The blenniid *Ophioblennius atlanticus* is a common shallow water shorefish inhabiting regions of primarily dead coral and cobble rock. Like many other members of its family, this species maintains a stable home range, generally about two meters in diameter. Individual fish forage over this more or less defined area in short bursts of feeding activity, biting detritus and fine algal layers from the substratum. The territory typically includes a station such as a particular rock or crack to which the fish returns between forays. Initial tagging experiments showed that when individuals were transplanted several meters from their home range, there was a tendency for them to return from such transfers.

A study of predation on tropical holothurians at Discovery Bay, Jamaica

By James D. Parrish, Graduate School of Oceanography, Univ. of Rhode Island, Kingston

Evidence is presented for predation on littoral holothurians by large gastropods in the lagoon behind a fringing reef at Discovery Bay, Jamaica. An observation of consumption of an *Actinopyga agassizi* by the triton *Charonia variegata* in the field was followed by observations in the laboratory of attacks by 4 specimens of *C. variegata* on 5 specimens of *A. agassizi* and by 5 specimens of *C. variegata* on 2 specimens of *Ludwigothuria mexicana*. In all, 4 *A. agassizi* and 2 *L. mexicana* were killed and eaten. There is strong evidence that *Isostichopus badionotus* is also attacked in the laboratory and in the field. The full sequence of attack and defensive behavior was observed in the laboratory. *Actinopyga agassizi* appears to release a noxious substance locally from the body surface under rather specific forms of irritation, including attack by *C. variegata*. This defense appears to be rather effective under some circumstances. Advanced hunger and periods of exposure in close proximity to the holothurian appear to give *C. variegata* sufficient resistance to the "noxin" to permit successful predation. Observations and repeated census in the field study area suggest that, based on numbers of holothurians and predaceous snails and normal range of movements, this predatory interaction may be of ecological importance.

Larval salinity acclimatization in the tropical shore crab, Sesarma ricordi

By Jon D. Standing, Dept. of Zoology, Univ. of California, Berkeley

Zoea of the euryhaline shore crab, *Sesarma ricordi*, from Jamaica, were collected in environments with high (36.8 ‰) and low (4.2 ‰) salinities and were subjected to ten acutely administered salinity conditions from 0 to 175% sea water for three days. One hundred percent of the high acclimatized zoea survived 100% S.W.; survival percentages decreased to forty-five percent at 25% S.W. and fifty-five percent at 150% S.W. By contrast, one hundred percent of the low acclimatized zoea survived the range from 10 to 100% S.W., and seventy and forty percent of the animals survived 5% and 150% S.W., respectively. More animals survive a graded salinity stress than an acute stress of the same magnitude and over the same time period. Hyperosmotic stresses in the supralittoral pool habitat of the larvae are gradual but often extremely high. Hypo-osmotic stresses after rains may be extremely low because of the inability of larvae to swim into well developed freshwater lenses (rain water tends to float as a layer on top of the salt water of the pools).

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FISH DIVERSITY ON A CORAL REEF IN THE VIRGIN ISLANDS

by Michael J. Risk

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FISH DIVERSITY ON A CORAL REEF IN THE VIRGIN ISLANDS

by Michael J. Risk[1]

INTRODUCTION

Terrestrial ecologists have accumulated data relating bird species diversity to foliage height diversity (MacArthur and MacArthur, 1961; MacArthur, 1964; Recher, 1969); complexity of foliage pattern seems to be a better predictor of bird species diversity than is the tree species diversity. There is some indication that a similar relationship exists on coral reefs, between fish species diversity and substrate complexity. Talbot (1965, p. 453), in comparing fish collections from areas with either few or many species of corals present, states "It is probable that the greater variety of coral species... allows for a more varied fish population than the single species," and, "It is probable that the more complex coral population in the mixed stand provides more ecological niches than are available in the single species stand." Hiatt and Strasburg (1960, p. 118) found more species and individuals on "ramose" than on "glomerate" coral heads: "Because glomerate coral heads are generally devoid of interstices in which small organisms can hide, such heads are visited only by fish species intent on browsing or grazing coral polyps." In a study on *Conus*, Kohn (1967, p. 257) found "Type III habitats are topographically the most complex... and these support the most diverse assemblages of *Conus*." The author attempted to measure the relationship between fish species diversity and the physical makeup of the coral substrate, following the work done on bird species diversity.

PROCEDURE

(a) *Study area*

The area selected was a portion of a low-lying, shallow patch reef located in the eastern part of Greater Lameshur Bay, St. John, Virgin Islands. Substrate types within the area were live coral *(Montastrea annularis, Millepora alcicornis, Porites furcata,* and *Agaricia agaricites)*, dead coral, sponges (mostly *Ircinia* spp.) and carbonate sand.

(b) *Sample locations*

Two transects were laid out in the form of a "T", with the upright perpendicular to the shore, and the crosspiece further offshore and parallel to the shoreline.

The "upright" transect began about 50 meters from shore, in 4 meters of water, and extended 16 meters seaward, to a depth of 4.5 meters. The "crosspiece" transect was also 16 meters long, and 4.5 meters deep throughout its length.

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(c) *Determination of fish species diversity, "Hf"*

Only territorial fishes were considered in this study. Several days were spent diving and observing in the area, in order to determine which species were territorial. When doubt existed about a particular fish, it was frightened into its home territory several times over the course of 2 or 3 days. Only fishes consistently returning to the same location were counted; appropriate members were three species of damselfish, a goby, a squirrelfish, and occasional filefishes, tangs, juvenile grunts and snappers. All caves, crevices, and holes were investigated, often using a light.

Numbers of individuals of the selected species were then determined in each of the sixteen quadrats. Each area was counted at least twice a day for a period of three days. To reduce operator bias, previous values recorded on underwater slates were left on shore, and the quadrats counted beginning at different ends of the two transects (see Appendix A).

Census values were in good agreement, and ranged from 4 to 7 species and from 7 to 21 individuals per square meter. Fish species diversity values were calculated using Shannon's formula for H' (Shannon, 1948).

(d) *Determination of substrate topographic complexity, "T"*

Actual surface area of a substrate as compared to its horizontal projection area was assumed to be a measure of spatial heterogeneity. The technique used was a modification of geological "point-counting," wherein volumes of constituents are assumed proportional to their representation along line transects. In the present study, actual surface area was assumed to be a function of actual linear dimensions.

The author used a fine-link chain, which could be draped and applied over a length of one meter. This was done eight times for each meter-square quadrat; in some cases four meters of chain were required to equal one "straight" meter.

Actual surface area was assumed proportional to the squares of these estimates of actual linear dimensions; therefore, the value of T for any one quadrat is the sum of the eight estimates, squared. These values are recorded in Appendix B.

(e) *Determination of substrate biological diversity "B"*

The substrate was arbitrarily divided into seven constituents: four species of living coral, dead coral, sponges, and carbonate sand. Different species of living coral were almost always separated by a band of dead coral; sponges grew only on this dead coral.

Each constituent type was assumed to have areal coverage proportional to its intersect length along line transects. Again, in each of the sixteen quadrats, intersect length were determined along eight one-meter line transects. The result for each quadrat was therefore a total length of eight meters, divided among up to seven constituents.

B was then calculated from these data, using Shannon's formula for H'; values for each quadrat are recorded in Appendix C.

(f) *Data processing*

Multiple regression analysis was performed on the data at the University of Southern California Computer Sciences Laboratory.

(g) *Underwater data gathering*

The author is familiar with data-gathering by SCUBA, having conducted benthic surveys and studies in a variety of non-tropical habitats. The amount of time and energy required to measure only sixteen sample areas was staggering.

For this study, the author spent 80 hours underwater; including the preliminary study, more than 800 fishes were identified, and their territories noted; intersect values for substrate types were determined (to the nearest millimeter) along 144 meters of reef, and 1,028 meters of chain were stretched over the reef surface. To measure each meter-square quadrat took at least five hours.

RESULTS

Significant relationships between the three main variables (H_f, T and B) were tested for. In addition, many subdivisions of the main variables, such as sand cover, total coral cover (live or dead), and total fishes, were investigated.

Significant correlation exists only between fish species diversity, H_f, and substrate topographic complexity, T. Results of analysis of the three main variables are given in Table 1.

Table 1. CORRELATION COEFFICIENT MATRIX

	H_f	T	B
H_f	1.000	*0.624	0.004
T	-	1.000	-0.161
B	-	-	1.000

*$p < 0.05$

Regression Equation: $H_f = 1.06 + 0.004T + 0.108B$

Multiple correlation coefficient 0.633.

H_f = fish species diversity ("nits")
T = substrate topographic complexity
B = substrate biological diversity

The regression coefficient for T is highly significant ($p < 0.01$); that for B is not significant. Increase in the multiple correlation coefficient on addition of the B effects to those of T is only 0.009.

DISCUSSION

Although the number of samples is quite small, there exists a striking positive correlation between fish species diversity and degree of substrate topographic complexity. This result is in accordance with predictions from terrestrial bird studies.

It is interesting that there is no significant correlation between fish species diversity and the biological nature of the substrate; the choice of a territory would seem to be controlled by predation pressure, rather than by feeding preferences.

There is also no significant positive correlation between total numbers of fishes and either substrate topographic complexity or substrate biological diversity; the relationship does not appear to be a simple one of "more holes, more fish." There apparently is occurring some selective partitioning of the habitat by individual fish species.

ACKNOWLEDGMENTS

Field work was carried out during the summer of 1969, when the author was a Teaching Assistant for the Organization for Tropical Studies course in Tropical Marine Biology. This was an invaluable opportunity to study and work on coral reefs.

Drs. Gerald J. Bakus and Peter W. Frank have been generous of their time in reading and criticizing the manuscript. Any remaining errors or omissions are the author's.

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APPENDIX A

POPULATIONS OF TERRITORIAL FISHES IN SAMPLE AREA

Transect No. 1 (Perpendicular to shore)

Quadrat No.	Eupomacentrus fuscus	Eupomacentrus planifrons	Microspathodon chrysurus	Gnatholepis thompsoni	Lutjanus sp. (juv.)	Haemulon sciurus	Holocentrus rufus	Acanthurus coerulens	Monacanthus tucheri	Hypoplectrus puella	Total No. of fishes
1 (shallow)	4	3	2	3	1	2	-	-	-	-	15
2	3	3	1	3	-	-	-	-	2	-	11
3	2	1	1	3	-	-	-	-	-	-	7
4	4	2	3	1	-	1	1	-	-	-	12
5	3	1	1	1	1	3	2	-	-	-	12
6	5	1	1	2	-	-	2	-	-	-	11
7	3	1	-	2	1	-	2	-	-	-	9
8 (deep)	2	3	1	-	-	-	6	-	-	-	12

Transect No. 2 (Parallel to shore)

Quadrat No.	Eupomacentrus fuscus	Eupomacentrus planifrons	Microspathodon chrysurus	Gnatholepis thompsoni	Lutjanus sp. (juv.)	Haemulon sciurus	Holocentrus rufus	Acanthurus coerulens	Monacanthus tucheri	Hypoplectrus puella	Total No. of fishes
1 (north)	2	3	1	6	-	-	-	1	-	-	13
2	3	1	2	4	1	-	-	1	-	-	12
3	3	2	1	6	-	-	-	-	-	1	13
4	3	2	1	5	1	-	-	-	-	-	12
5	5	2	-	3	-	-	-	1	-	-	11
6	7	4	4	4	-	-	-	2	-	-	21
7	3	4	1	4	-	-	-	-	-	-	12
8 (south)	2	3	5	8	-	-	-	-	-	1	19

APPENDIX B

VALUES OF T, SUBSTRATE TOPOGRAPHIC COMPLEXITY (m^2)

Transect No. 1		Transect No. 2	
Quadrat No.	T	Quadrat No.	T
1 (shallow)	75.5	1 (north)	36.5
2	95.7	2	73.6
3	28.2	3	21.3
4	97.2	4	44.2
5	85.8	5	35.4
6	97.1	6	84.1
7	103.1	7	53.7
8 (deep)	37.2	8 (south)	60.0

APPENDIX C

VALUE OF B, SUBSTRATE BIOLOGICAL DIVERSITY ("nits")

Transect No. 1		Transect No. 2	
Quadrat No.	B	Quadrat No.	B
1 (shallow)	1.34	1 (north)	1.21
2	1.23	2	1.40
3	1.17	3	1.06
4	1.12	4	1.34
5	1.34	5	1.43
6	0.98	6	1.23
7	1.11	7	1.68
8 (deep)	1.17	8 (south)	1.08

ATOLL RESEARCH BULLETIN
No. 154

RECOLONIZATION OF A POPULATION OF SUPRATIDAL FISHES AT ENIWETOK ATOLL, MARSHALL ISLANDS

by William A. Bussing

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RECOLONIZATION OF A POPULATION OF SUPRATIDAL FISHES AT ENIWETOK ATOLL, MARSHALL ISLANDS

by William A. Bussing[1]

INTRODUCTION

The field work and most of the identifications of fishes for this study were carried out during July 1965 at the Eniwetok Marine Biological Laboratory of the University of Hawaii while I was assisting Dr. Gerald J. Bakus in a study of the grazing effects of reef fishes. A small supratidal pool was noticed near a large quarry which we visited frequently during the fish-grazing study. Rotenone was applied to the pool early in July and yielded a large number of fishes and an especially large biomass of the moray eel *Gymnothorax picta*. It was decided at that time to repoison the pool at the end of July and compare the species composition, biomass and ecology of the fishes present in each collection in order to ascertain the rate and manner of recolonization of the fish population and something about its trophic structure.

The phenomenon of plant succession has been frequently discussed and is rather well known. The accompaying animal succession has been less well studied, but seems to closely follow the same pattern as plant succession, e.g. certain pioneer species appear initially and are replaced by a sequential series of populations until a relatively stable climax community is established. Numerous studies have been done on succession of protozoa in culture jars (Bick, 1967a; 1967b), on the establishment of marine invertebrate communities on newly constructed or specially prepared substrates (Reish, 1964, Poore, 1968) and on seral succession of fishes in ponds and marshes (Shelford, 1911a; 1911b). All these animal succession studies really involve plant succession as well. In both cases the flora and fauna are concurrently undergoing seral changes. The present study is unique in that only the fish population (and certain invertebrate species) were removed from the community. The rather sparse algal community was not apparently affected directly by the ichthyocide.

DESCRIPTION OF HABITAT

A general description of the Marshall Islands and their climate has been given by Hiatt and Strasburg (1960). The tidepool under consideration was located on the windward reef side of Eniwetok Island ($11^{\circ}21'$N; $162^{\circ}20'$E) one of the chain of islands forming Eniwetok Atoll. The pool, although facing the open sea, was protected from excessive wave action by a shallow reef flat which extended about 200 meters offshore. With the aid of Coast and Geodetic Survey tide tables, the surface of the tidepool was estimated to lie about .95 m above mean sea level. Daily high tides progressed from 1.1 m on July 7 to 1.6 m on July 29. Thus, the pool in question was flooded daily throughout the study period.

The measured range of temperature variation in the pool during the study period was from 28° to 32°C. The lowest reading was taken in the morning on a rainy overcast day and probably

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approximates the true low temperature for the pool during July. The highest temperature was recorded at midday on July 7, although this was surely surpassed on other days when measurements were not taken. The water in the pool was generally clear, but turned slightly brown in color after several hours of insolation.

The study pool consisted of a 20 m by 40 m depression in old limestone pavement. The depth was a rather uniform 0.2 m, but at one point reached 0.4 m. The sides and much of the bottom consisted of coral rock and rubble; part of the bottom was covered by sand.

Little life except a few fish were evident at first glance, but a considerable number of fishes of different species were collected by poisoning. Other conspicuous larger organisms revealed by turning over rocks and by the poison were xanthid crabs, hermit crabs (Diogenidae) and octopods. The flora consisted principally of green and blue-green filamentous algae.

MATERIALS AND METHODS

All fishes were collected with dip nets and by hand after poisoning with Pro-Noxfish. Two collections were made: on July 7 and 22 days later on July 29. The behavior of fishes was observed intermittently before July 7 and during the period between the two collections. The majority of the fishes were identified at the Eniwetok Marine Biological Laboratory by means of the literature and by comparison with Laboratory reference specimens identified by Dr. John Randall. Specimens of each species were counted, the ranges in standard length taken and the moist formalin weight recorded. Later, the average weight was computed for each species in both collections (Table 1).

The trophic level of each species of fish was determined using Hiatt and Strasburg (1960) where applicable. Direct examination of gut contents was made in other cases and on 15 specimens of *Gymnothorax picta*.

The percentages by weight of herbivorous, omnivorous and carnivorous fishes were calculated for each collection (Table 2). Percentages for the first collection were determined twice: once including all fishes and the other excluding the moray eel *Gymnothorax picta*. This was done in order to better compare the trophic structure of each collection, because *G. picta* accounted for such a large percentage (44.8%) of the total biomass of the first collection and was absent from the second collection.

TROPHIC STRUCTURE OF THE FISH POPULATION

Little has been said about the community organization of tidepools. I have been unable to find any reports on the trophic structure of the fishes of a tidepool community.

Carnivorous or partially carnivorous fishes make up the greatest biomass in the first collection even if *G. picta* is excluded from the calculation. These top-heavy pyramids are, of course, based on fishes alone and do not represent the complete trophic structure of the pool. Likewise, such a predominance of secondary consumers is not surprising in a zone which receives daily a great accumulation of organic matter from the highly productive neritic zone.

When biomass distribution of the first collection (excluding *G. picta*) is compared with the trophic structure of the second collection it is seen that the percentages of fishes representing different trophic levels is roughly comparable (Table 2). Thus, the original trophic structure of the fish population was re-established within three weeks or sooner after the initial poisoning.

RECOLONIZATION OF THE FISH POPULATION

Thirty-three species belonging to 16 families were present in the two collections. Only five species, a snapper *(Lutjanus gibbus)*, two tangs *(Acanthurus elongatus* and *A. nigricans)* and two puffers *(Arothron meleagris* and *A. nigropunctatus)* were present in the second collection, but not in the first.

The species diversity was strikingly reduced in the second collection, although each family taken in Collection No. 1 was usually represented in the second collection by some specimens of the commonest species of that family. The total fish biomass was also greatly reduced even though the pool was inhabited by fishes the day after the poisoning, and free access to the pool was possible at least once a day (high tides of 1.1 to 1.6 m) during the three weeks between poisonings. The average size of specimens in Collection No. 1 was 5.26 gm (3.02 gm excluding *G. picta)* compared to 0.362 gm in Collection No. 2. At 1300 hours on the day following the first poisoning, several small specimens of *Abudefduf glaucus*, *Istiblennius edentulus* and *I. lineatus* were seen behaving normally. The pool apparently had been washed clean of poison and these fishes had gained entry to the pool during the high of 1.1 m at 0105 hours the night before. Two small morays *(Gymnothorax bikiniensis)* were seen lying on their backs in the middle of the pool at this time. Both were nearly dead and had probably entered the pool at night before it had been completely rinsed of poison.

Juveniles of the commonest species showed the greatest ability to repopulate the pool. Small specimens of *Abudefduf glaucus* and *Istiblennius edentulus* accounted for the majority, by weight and number, of the fishes taken in the second collection. Adults of the above mentioned species are territorial to a varying degree and perhaps for this reason adults from surrounding waters did not readily reach the barren pool. This, however, does not explain the lack of the species which do not exhibit territorial behavior.

In addition to the fishes, the only macroscopic organisms which appeared to be affected by rotenone were octopods and shrimps. Xanthid crabs and hermit crabs were not killed, and appeared to occur in equal numbers after the poisoning. The death of shrimps and possibly many smaller invertebrates could explain the decrease in numbers of omnivores and carnivores. Filamentous algae, the principal producer in the pool, seemed unaffected, but supported a much smaller herbivore population after the poisoning; acanthurids and mugilids decreased greatly in numbers and weight.

Young of the snapper *Lutjanus gibbus* appear to have replaced the four species of *Epinephelus* which were taken in the first collection. These species seem to have similar niches when young. They are carnivores and lurk around and under ledges searching for prey. The puffer *Canthigaster solandri* was collected in equal numbers (10) in both collections, but the day before the second collection an estimated 200-300 specimens were observed in the same pool. Thus the day to day fluctuation in numbers of certain species is very great and much useful information could be obtained by daily poisoning of such a tide pool.

The reduction of the invertebrate fauna by rotenone may partially explain the reduction in the fish population, but probably several other factors were involved. Perhaps the pool, while no longer poisonous to fishes, retained an odor of rotenone which was disagreeable to some species for several weeks. Tidepools may be populated irregularly, depending upon breeding periods and tidal amplitude. Certain fishes are quite wary when placed in an uninhabited aquarium and never behave normally unless surrounding by numbers of other fishes. Fishes washed into an uninhabited tidepool may experience this same sensation and avoid such a tidepool. Very small fishes are likely to be washed from pool to pool frequently, but many become territorial and remain in the same pool much longer when they reach a larger size. This may partially explain why very small fishes are the principal "pioneers" of a recently poisoned pool.

ACKNOWLEDGEMENTS

I am grateful to Gerald J. Bakus for encouraging this study and for his criticism of the manuscript, to Robert W. Hiatt of the University of Hawaii and the United States Atomic Energy Commission for making the study possible and to Janet Haig of the Allan Hancock Foundation for identification of the invertebrates collected during the study.

SUMMARY

It has been shown that three weeks after poisoning a tidepool with rotenone the fish population was much reduced in species diversity, numbers and biomass, although the trophic structure was not greatly altered. Reduction of invertebrates, odor of rotenone and habits of juvenile fishes are cited as possible reasons for a delay in repopulation of the pool.

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Table 1. A COMPARISON OF NUMBERS OF SPECIMENS, TOTAL WEIGHT, AVERAGE WEIGHT AND LENGTH OF SPECIMENS FROM FIRST AND SECOND COLLECTIONS

		COLLECTION NO. 1				COLLECTION NO. 2			
Species	Trophic Level	n	Weight (gm)	$\bar{x}$	Standard Length (mm)	n	Weight (gm)	$\bar{x}$	Standard Length (mm)
Muraenidae									
Gymnothorax picta	C	18	2357	130.9	61.8-605				
Holocentridae									
Holocentrus lacteoguttatus	C	6	29.5	4.9	47.4-67.2	1	2.7	2.7	45
Holocentrus sammara	C	1	1.1	1.1	35.7				
Holocentrus tieroides	C	1	3.2	3.2	48.1				
Mugilidae									
Crenimugil crenilabis	H	24	137.1	5.7	52.7-76.7	2	0.9	0.5	26.3-32.5
Neomyxus chaptalii	H	6	35.4	5.9	60.0-76.8				
Mugil cephalus	H	39	54.3	1.4	24.0-69.6				
Serranidae									
Epinephelus melanostigma	C	22	257.4	11.7	55.0-104				
Epinephelus spilotoceps	C	10	49.4	4.9	58.0-63.7				
Epinephelus merra	C	4	68.6	17.2	71.1-86.5				
Epinephelus socialis	C	4	73.6	18.4	75.2-105				
Lutjanidae									
Lutjanus gibbus	C					29	17.6	0.6	22.2-50.7
Kuhlidae									
Kuhlia taeniura	C	2	8.1	4.1	56.2-58.0				
Kuhlia marginata	C	1	1.8	1.8	43.6				
Mullidae									
Mulloidichthys samoensis	C	11	85.5	7.8	77.1-83.9				
Chaetodontidae									
Chaetodon lunula	O	1	6.4	6.4	50.8	1	0.4	0.4	19
Centropyge flavissimus	H	1	0.4	0.4	19.0				

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Table 1. (cont.)

Species	Trophic Level	COLLECTION NO. 1 n	Weight (gm)	$\bar{x}$	Standard Length (mm)	COLLECTION NO. 2 n	Weight (gm)	$\bar{x}$	Standard Length (mm)
Acanthuridae									
Acanthurus triostegus	H	152	372.5	2.5	22.5-54	28	16.9	0.6	22.0-27.5
Acanthurus elongatus	H					1	0.8	0.8	28.0
Acanthurus nigricans	H					2	1.6	0.8	26.9-28.0
Pomacentridae									
Abudefduf glaucus	O	331	438.3	1.3	13.0-51	317	48.1	0.2	12.5-24.0
Abudefduf sordidus	O	8	25.9	3.2	30.0-61.2	1	0.2	0.2	18.0
Labridae									
Thalassoma umbrostygma	C	1	0.4	0.4	28.0				
Gobiidae									
Bathygobius fuscus	C	75	224.6	3.0	13.7-77.0	13	13.9	1.1	11.5-55
Pandaka pruinosa	C	2	0.25	0.1	18.0				
Kelloggella oligolepis	C	3	0.05	0.05	13.5-17.1				
Blenniidae									
Istiblennius edentulus	O	215	981.3	4.6	12.4-102	55	42.6	0.8	18.9-78.0
Istiblennius lineatus	O	8	28.4	3.6	25.1-86.5	5	15.3	3.1	37.4-85.5
Istiblennius paulus	O	1	0.25	0.25	37.2				
Tripterigiidae									
Tripterygion minutus	C	1	0.05	0.05	18.3				
Tetraodontidae									
Arothron meleagris	O					1	0.6	0.6	17.6
Arothron nigropunctatus	O					1	0.5	0.5	16.3
Canthigasteridae									
Canthigaster solandri	H	10	15.0	1.5	18.6-38.9	10	6.8	0.7	17.0-29.0
Totals		958	5255.8	5.26		467	168.9	.362	

Table 2. BIOMASS IN GRAMS AND PERCENT OF TOTAL FOR EACH TROPHIC LEVEL FROM THE FIRST AND SECOND COLLECTIONS

COLLECTION NO. 1 (TOTAL FISHES)

	gm	%
Herbivores	614.7	11.7
Omnivores	1480.6	28.2
Carnivores	3160.5	60.1
	5255.8	100.0

COLLECTION NO. 1 (TOTAL FISHES EXCLUDING *G. PICTA)*

	gm	%
Herbivores	614.7	21.2
Omnivores	1480.6	51.1
Carnivores	803.5	27.7
	2898.8	100.0

COLLECTION NO. 2 (TOTAL FISHES)

	gm	%
Herbivores	27.0	16.0
Omnivores	107.7	63.8
Carnivores	34.2	20.2
	168.9	100.0

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SOME MARINE BENTHIC ALGAE FROM TRUK AND KUOP, CAROLINE ISLANDS

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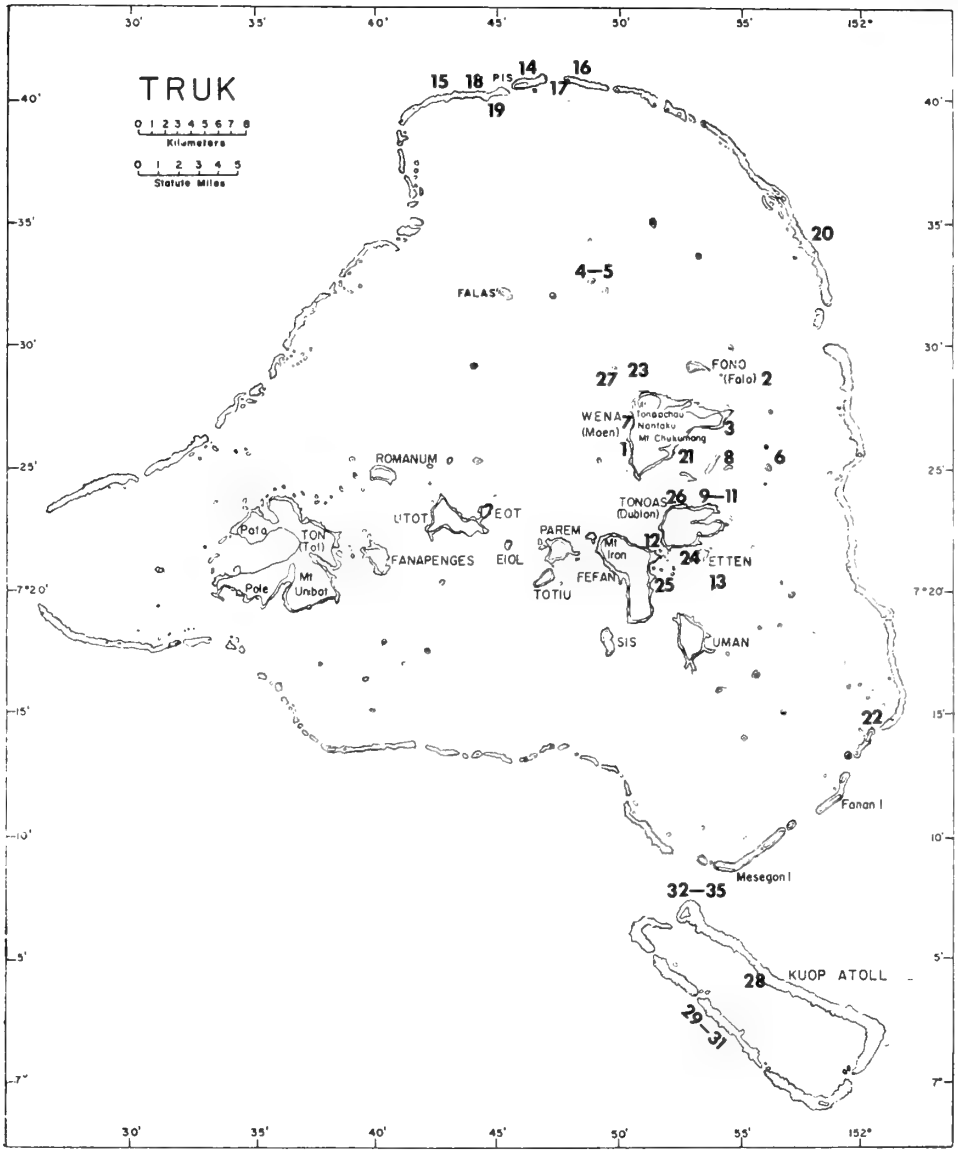

Figure 1. Map of Truk and Kuop showing collecting sites (map taken from Gressitt, 1954).

SOME MARINE BENTHIC ALGAE FROM TRUK AND KUOP, CAROLINE ISLANDS[1]

by Roy T. Tsuda[2]

INTRODUCTION

Truk (Fig. 1) consists of a lagoon, with about 40 volcanic islands and several reef patches, encircled by a barrier reef. The lagoon is from 45 to 65 kilometers in diameter and ranges in depth to 75 meters. Fringing reefs prevail along the coast of the larger lagoon islands. Wave-washed benches, which are present along the windward coast of non-lagoon volcanic islands, are absent. The barrier reef with its numerous passages is about 225 km in circumference and has approximately 50 small coral islets. Most of the barrier reef is awash during low tides. Kuop Atoll lies only three km south of the southernmost terminus of the Truk barrier reef and for the purpose of algal distribution is merely a southern extension of Truk.

Past records of marine benthic algae from Truk can be found in seven publications, while marine algae from Kuop Atoll have not been reported to date. The first paper to list marine algae from Truk was published by Okamura (1916) who cites 27 species. In a systematic compilation of 484 species of marine algae from the Pacific Ocean, Schmidt (1928) includes all the species reported by Okamura and four additional species from Truk.

During the summer of 1960, Mr. Ernani Menez, presently with the Smithsonian Oceanographic Sorting Center, made a rather extensive collection of marine benthic algae from several islands in the Caroline Islands while a member of the Miami University-Collegiate Rebel Expedition to Micronesia. The collections were stored in the Department of Botany of the University of Hawaii until 1964 when Dr. Gavino Trono, Jr., presently with the University of the Philippines, undertook the task of identifying the specimens as part of his Ph.D. dissertation under the direction of Dr. Maxwell S. Doty. In the same year, Dr. George J. Hollenberg of the University of Redlands arrived at the University of Hawaii to resume his studies on the red algal genera *Polysiphonia* and *Herposiphonia*, and incorporated those specimens that he had examined from the Caroline Islands into his papers (Hollenberg, 1968a, 1968b, 1968c). These publications include four species of *Polysiphonia* and four species of *Herposiphonia* from Truk. The results of Dr. Trono's study on the marine benthic algae from the Caroline Islands were published in two parts. Part I (Trono, 1968) lists 42 species of blue-green and green algae from Truk, while Part II (Trono, 1969) includes 48 species of brown and red algae from Truk and also incorporates the eight species reported by Dr. Hollenberg. Altogether, in the above mentioned papers, 102 species of marine benthic algae have been reported from Truk.

Recently, opportunities to make additional collections of marine algae on Truk and Kuop have arisen in conjunction with the "crown-of-thorns" starfish, *Acanthaster planci*, studies in Micronesia. Mr. Richard H. Randall of the University of Guam took the initiative to make a

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moderate collection of marine algae from Truk and Kuop during the Westinghouse *Acanthaster* survey in the summer of 1969. The following summer, the author was able to make additional collections of algae when he participated as member of the University of Guam's *Acanthaster* monitoring team.

The purpose of this paper is to provide a checklist of the species collected by Mr. Randall and the author. Seven additional specimens collected by Mr. Astèrio Takesy, formerly a student at the University of Guam, are also incorporated in this paper.

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The author is grateful to Mr. Wyman X. Zachary, Director of Resources and Development, and to Mr. Peter T. Wilson, Fisheries Management Biologist, both of the Trust Territory of the Pacific Islands, for their financial and logistic support during the author's stay on Truk. The author acknowledges the help of Dr. Robert S. Jones, Director of the University of Guam's Marine Laboratory, Mr. M. Rodney Struck, staff member of the University of Guam's Marine Laboratory, and Mr. Milton McDonald, Starfish Control Specialist for Trust Territory, who served as diving companions and at times contributed specimens to the overall collections.

STATION DESCRIPTIONS

The following is a listing of the 35 algal collecting stations which can be located on Fig. 1. The stations for Truk and Kuop are numbered consecutively but are separated merely for convenience. Information for each station includes 1) the specific island from which the collection was made, 2) a brief description of the habitat, i.e., zone and depth, 3) name of collector, 4) date of collection and 5) the collection number(s) assigned to the algae at each station.

Truk (7°28'N, 151°52'E)

STATION 1: Moen I., Mwaan Village, reef flat, 1 m deep, legit A. Takesy, May, 1969 (RT 2856-2861).

2: Osakura I., lagoon slope, 7 m deep on dead coral rubble, legit R.H. Randall, July 6, 1969 (RHR 359).

3: Moen I., east end, lagoon slope, 3-7 m deep on dead coral rubble, legit Randall, July 7, 1969 (RHR 369).

4: Fanuet I., reef margin, nearly awash, legit Randall, July 10, 1969 (RHR 371).

5: Fanuet I., lagoon slope, 3 m deep attached to dead *Acropora*, legit Randall, July 10, 1969 (RHR 372).

6: Herit I., reef flat and lagoon slope, .3-3 m deep, legit Randall, July 18, 1969 (RHR 368).

7: Moen I., Government Dock outside of Fisheries Office, .5 m deep on cement wall, legit R.T. Tsuda, June 13, 1970 (RT 3367-3368).

8: Yanagi I., west lagoon slope, 10-17 m deep on dead *Acropora* and coral rubble, legit Tsuda, June 13, 1970 (RT 3370-3387).

9: Dublon I., north reef flat, .3 m deep on dead coral and sand, legit Tsuda, June 13, 1970 (RT 3388-3402).

STATION 10: Dublon I., north lagoon slope, 3-7 m deep in live *Acropora* bed, legit Tsuda, June 13, 1970 (RT 3405-3408).

11: Dublon I., north lagoon floor, 17 m deep on coral rubble and sand, legit R.S. Jones, June 13, 1970 (RT 3413-3415).

12: Reef patch, .5 km SW of Dublon I., 2 m deep, legit Tsuda, June 14, 1970 (RT 3416-3417).

13: Sunken Japanese Ship, ca. 4 km SE of Etten I., 20-30 m deep, legit Tsuda, June 14, 1970 (RT 3419-3434).

14: Pis I., seaward side, intertidal zone, legit Tsuda, June 15, 1970 (RT 3437-3441).

15: Pis I., west of channel, seaward reef margin (exposed) and seaward reef front (1 m deep), legit Tsuda, June 16, 1970 (RT 3442-3449).

16: Pis I., east of channel, seaward slope, 15-35 m deep, legit Tsuda, June 16, 1970 (RT 3451-3461).

17: North Pass, channel slope, 10-30 m deep, legit Tsuda, June 17, 1970 (RT 3462-3463).

18: Pis I., west of channel, seaward slope, 45 m deep on dead coral, legit Tsuda, June 17, 1970 (RT 3465-3466).

19: Pis I., boat harbor, 1 m deep near shore, legit Tsuda, June 17, 1970 (RT 3467).

20: Liball I., reef flat, .3-1 m deep, legit Tsuda, June 17, 1970 (RT 3469-3487).

21: Moen I., Wiicap, mangrove area, reef flat and reef front., .3-2 m deep, legit Tsuda, June 18, 1970 (RT 3488-3505).

22: Salat I., east coast, lagoon slope, 5 m deep, legit Tsuda, June 19, 1970 (RT 3508-3514).

23: Drift, north of Moen I., legit Tsuda, June 19, 1970 (RT 3515).

24: Etten I., reef flat, .5-1 m deep, legit Tsuda, June 20, 1970 (RT 3518-3519).

25: Sunken Japanese Destroyer, east coast of Fefan I., 10-30 m deep, legit Tsuda, June 20, 1970 (RT 3520-3535).

26: Sunken Japanese Tanker, northwest coast of Dublon I., 10-30 m deep, legit Tsuda, June 20, 1970 (RT 3536-3546).

27: Scheiben I., lagoon slope, 7 m deep, legit Tsuda, June 23, 1970 (RT 3558-3561).

Kuop (6°59' N, 151°59' E)

28: Lagoon reef, 1-2 m deep on sand and coral, legit Randall, July 12, 1969 (RHR 360).

29: Southwest side of atoll, seaward reef front, 7 m deep, legit Randall, July 13, 1969 (RHR 364).

STATION 30: Southwest side of atoll, seaward reef margin, awash, legit Randall, July 13, 1969 (RHR 365a).

31: Southwest side of atoll, seaward reef front, 7 m deep, legit Randall, July 13, 1969 (RHR 365b-d).

32: Northwest side of atoll, seaward submarine cliff, 16-40 m deep, legit Randall, July 13, 1969 (RHR 366).

33: Northwest side of atoll, seaward submarine cliff, 3-16 m deep, legit Randall, July 13, 1969 (RHR 367).

34: Northwest side of atoll, seaward reef flat and margin, exposed to .3 m deep, legit Tsuda, June 21, 1970 (RT 3547-3550).

35: Northwest side of atoll, seaward submarine cliff, 10-30 m deep, legit Tsuda, June 21, 1970 (RT 3552-3557).

SPECIES LISTING

The following list includes specimens collected by A. Takesy (May 1969), R.H. Randall (July 1969) and the author (June 1970). All specimens are catalogued in the University of Guam Herbarium. Species preceded by an asterisk represent new records from Truk.

DIVISION CYANOPHYTA (blue-green algae)

Order Oscillatoriales

**Calothrix confervicola* (Roth) Ag.
TRUK: Sta. 15 (RT 3443).

**Hormothamnion solutum* Bornet & Flahault
TRUK: Sta. 21 (RT 3488).

Microcoleus lyngbyaceus (Kütz.) Crouan
TRUK: Sta. 6 (RHR 368e), Sta. 8 (RT 3370, RT 3382), Sta. 9 (RT 3399), Sta. 13 (RT 3430), Sta. 22 (RT 3510), Sta. 25 (RT 3523).
The specimens vary from 13 to 40 μ in diameter.

Schizothrix calcicola Gomont
TRUK: Sta. 8 (RT 3371).
The specimen appears as a gelatinous ball with individual filaments 1 to 1.5 μ in diameter.

**Schizothrix mexicana* Gomont
TRUK: Sta. 4 (RHR 371a), Sta. 8 (RT 3383), Sta. 15 (RT 3445), Sta. 22 (RT 3511).

**Spirulina subsalsa* Gomont
TRUK: Sta. 9 (RT 3399, intermixed with *Microcoleus lyngbyaceus*).

DIVISION CHLOROPHYTA (green algae)

Order Ulotrichales

**Enteromorpha clathrata* (Roth) Ag.
TRUK: Sta 14 (RT 3441).
The specimen consists of an immature branched thallus about 5 mm high.

Order Cladophorales

Rhizoclonium samoense Setchell
TRUK: Sta. 14 (RT 3439).

Order Siphonales

Bryopsis pennata Lamx.
TRUK: Sta. 20 (RT 3470), Sta. 25 (RT 3528).

**Caulerpa ambigua* Okamura
TRUK: Sta. 13 (RT 3433b).

Caulerpa brachypus Harvey
TRUK: Sta. 8 (RT 3372), Sta. 13 (RT 3426), Sta. 25 (RT 3529), Sta. 26 (RT 3541).
The latter three specimens collected from sunken ships possess thin delicate elongated blades.

Caulerpa cupressoides (West) C. Ag.
TRUK: Sta. 9 (RT 3396).

**Caulerpa filicoides* Yamada
TRUK: Sta. 13 (RT 3425), Sta. 26 (RT 3546).
This species was one of the most dominant algae found on the sunken ships.

Caulerpa lentillifera J. Ag.
TRUK: Sta. 11 (RT 3413), Sta. 13 (RT 3429), Sta. 26 (RT 3544).

Caulerpa racemosa (Forskål) J. Ag.
TRUK: Sta. 6 (RHR 368b), Sta. 8 (RT 3373), Sta. 9 (RT 3392), Sta. 18 (RT 3465), Sta. 20 (RT 3473), Sta. 21 (RT 3492), Sta. 25 (RT 3525, RT 3533).
KUOP: Sta. 35 (RT 3555).

Caulerpa serrulata (Forskål) J. Ag.
TRUK: Sta. 19 (RT 3467), Sta. 22 (RT 3513).
KUOP: Sta. 35 (RT 3554).

Caulerpa sertularioides (Gmel.) Howe
TRUK: Sta. 9 (RT 3390), Sta. 21 (RT 3495), Sta. 26 (RT 3540).

Caulerpa taxifolia (Vahl) C. Ag.
TRUK: Sta. 20 (RT 3481).

Caulerpa urvilliana Montagne
TRUK: Sta. 20 (RT 3476).
KUOP: Sta. 28 (RHR 360b).

**Caulerpa verticillata* J. Ag.
TRUK: Sta. 21 (RT 3496).

Chlorodesmis fastigiata (C. Ag.) Ducker
TRUK: Sta. 16 (RT 3460).
KUOP: Sta. 34 (RT 3549).

Chlorodesmis hildebrandtii A. & E.S. Gepp
TRUK: Sta. 16 (RT 3491, epiphytic on *Halimeda*).

Codium edule Silva
TRUK: Sta. 15 (RT 3446).
This specimen consists of only a fragment about 3 cm long.

**Halimeda copiosa* Goreau & Graham
TRUK: Sta. 6 (RHR 368c), Sta. 10 (RT 3406), Sta. 12 (RT 3416), Sta. 13 (RT 3422, RT 3427b), Sta. 16 (RT 3459), Sta. 25 (RT 3532), Sta. 26 (RT 3545).
KUOP: Sta 31 (RHR 365b), Sta. 32 (RHR 366a), Sta. 35 (RT 3553).

Halimeda cylindracea Decaisne
TRUK: Sta 21 (RT 3505), Sta. 22 (RT 3508), Sta 24 (RT 3519), Sta 27 (RT 3560).

Halimeda discoidea Decaisne
TRUK: Sta. 8 (RT 3374), Sta. 9 (RT 3391), Sta. 13 (RT 3427), Sta. 16 (RT 3458), Sta. 20 (RT 3480), Sta. 25 (RT 3521), Sta. 26 (RT 3537).
KUOP: Sta. 29 (RHR 364c)

**Halimeda gigas* Taylor
TRUK: Sta. 8 (RT 3375), Sta. 11 (RT 3415), Sta. 13 (RT 3421), Sta. 21 (RT 3493), Sta. 26 (RT 3543).

**Halimeda gracilis* Harvey
TRUK: Sta. 15 (RT 3447), Sta. 17 (RT 3462).
KUOP: Sta. 29 (RHR 364a).

Halimeda incrassata (Ellis) Lamx.
TRUK: Sta. 7 (RT 3667), Sta. 8 (RT 3377), Sta. 10 (RT 3405), Sta. 16 (RT 3456), Sta. 21 (RT 3501), Sta. 26 (RT 3536), Sta. 27 (RT 3559).
KUOP: Sta 29 (RHR 364b), Sta. 31 (RHR 365c).

Halimeda macroloba Decaisne
TRUK: Sta. 9 (RT 3388), Sta. 21 (RT 3494).

Halimeda macrophysa Askenasy
TRUK: Sta. 10 (RT 3408), Sta. 16 (RT 3457), Sta. 25 (RT 3520), Sta. 27 (RT 3558).

**Halimeda micronesica* Yamada
TRUK: Sta. 20 (RT 3479).
KUOP: Sta. 29 (RHR 364d).

Halimeda opuntia (L.) Lamx.
TRUK: Sta. 4 (RHR 371b), Sta. 8 (RT 3384), Sta. 9 (RT 3397), Sta. 20 (RT 3478).

**Halimeda simulans* Howe
TRUK: Sta. 9 (RT 3389), Sta. 21 (RT 3497).

**Halimeda stuposa* Taylor
TRUK: Sta. 20 (RT 3482).
KUOP: Sta. 28 (RHR 360a).

Rhipilia orientalis A. & E.S. Gepp
TRUK: Sta. 8 (RT 3380), Sta. 25 (RT 3523), Sta. 26 (RT 3542).

**Rhipilia tomentosa* Kütz.
TRUK: Sta. 16 (RT 3455).
Specimen heretofore known only from the Atlantic Ocean represents the first record from the Pacific region.

Tydemania expeditionis Weber van Bosse
TRUK: Sta. 8 (RT 3386), Sta. 13 (RT 3420, RT 3423), Sta. 25 (RT 3524).
Both the flabellate and the glomerulous forms are represented in the collections. The flabellate form was dominant on the sunken Japanese ships.

Udotea argentea Zanardini
TRUK: Sta. 8 (RT 3379), Sta. 25 (RT 3522).
KUOP: Sta. 28 (RHR 360d), Sta. 32 (RHR 366d).

**Udotea geppii* Yamada
TRUK: Sta. 13 (RT 3419), Sta. 25 (RT 3530).
KUOP: Sta. 28 (RHR 360e), Sta. 35 (RT 3552).

**Udotea palmetta* Decaisne
TRUK: Sta. 20 (RT 3475).
KUOP: Sta. 28 (RHR 360f).

Order Siphonocladales

Boergesenia forbesii (Harv.) Feldmann
TRUK: Sta. 22 (RT 3509).

Cladophoropsis membranacea (Ag.) Boerg.
TRUK: Sta. 22 (RT 3512).

**Dictyosphaeria cavernosa* (Forskål) Boerg.
TRUK: Sta. 13 (RT 3424), Sta. 20 (RT 3484).
KUOP: Sta. 34 (RT 3550).

Microdictyon okamurai Setchell
TRUK: Sta. 2 (RHR 359c), Sta. 20 (RT 3477).
KUOP: Sta. 28 (RHR 360c), Sta. 33 (RHR 367b), Sta 35 (RT 3556).

Valonia ventricosa J. Ag.
TRUK: Sta. 8 (RT 3381).

Order Dasycladales

**Acetabularia clavata* Yamada
TRUK: Sta. 15 (RT 3444b).
The collection is represented by a single specimen, 1 mm high.

Neomeris vanbosseae Howe
TRUK: Sta. 14 (RT 3440), Sta. 20 (RT 3472), Sta. 21 (RT 3503).

DIVISION PHAEOPHYTA (Brown algae)

Order Dictyotales

Dictyopteris repens (Okamura) Boerg.
TRUK: Sta. 13 (RT 3431), Sta. 15 (RT 3444a), Sta. 16 (RT 3451).

**Dictyota apiculata* J. Ag.
TRUK: Sta. 16 (RT 3452), Sta. 21 (RT 3500b).

Dictyota bartayresii Lamx.
TRUK: Sta. 5 (RHR 372b), Sta. 8 (RT 3385), Sta. 11 (RT 3414), Sta. 13 (RT 3434), Sta. 24 (RT 3518), Sta. 26 (RT 3539), Sta. 27 (RT 3561).

**Dictyota patens* J. Ag.
TRUK: Sta. 4 (RHR 371c), Sta. 21 (RT 3500a).

Lobophora variegata (Lamx.) Womersley
TRUK: Sta. 5 (RHR 372c), Sta. 8 (RT 3387), Sta 13 (RT 3428), Sta. 15 (RT 3449), Sta. 16 (RT 3454), Sta. 18 (RT 3466), Sta. 20 (RT 3471, RT 3483).

Padina boryana Thivy
TRUK: Sta. 7 (RT 3368), Sta. 9 (RT 3398), Sta. 21 (RT 3502).

**Padina* sp.
TRUK: Sta. 8 (RT 3378), Sta. 13 (RT 3432), Sta. 20 (RT 3487, sterile), Sta. 25 (RT 3531).

**Zonaria hawaiiensis* Doty & Newhouse
TRUK: Sta. 8 (RT 3376).
The specimen represents the first collection made outside of Hawaii where it was originally described as a new species.

Order Dictyosiphonales

Hydroclathrus clathratus (Bory) Howe
TRUK: Sta. 9 (RT 3400), Sta. 21 (RT 3499).

Order Fucales

**Sargassum duplicatum* J. Ag.
TRUK: Sta. 23 (RT 3515).

**Sargassum* sp.
TRUK: Sta. 6 (RHR 368c).
This specimen resembles *S. duplicatum* except for a cylindrical stem.

Turbinaria ornata (Turn) J. Ag.
TRUK: Sta. 9 (RT 3393), Sta. 14 (RT 3438), Sta. 15 (RT 3448).
KUOP: Sta. 30 (RHR 365a).

DIVISION RHODOPHYTA (red algae)

Order Nemalionales

Actinotrichia fragilis (Forskål) Boerg.
TRUK: Sta. 2 (RHR 359f), Sta. 21 (RT 3489).

**Galaxaura fasciculata* Kjellman
TRUK: Sta. 12 (RT 3417), Sta. 25 (RT 3535).

**Galaxaura fastigiata* Decaisne
TRUK: Sta. 25 (RT 3527).

**Galaxaura oblongata* (Ellis & Solander) Lamx.
TRUK: Sta. 2 (RHR 359e).

Order Cryptonemiales

Amphiroa foliacea Lamx.
TRUK: Sta. 2 (RHR 359d), Sta. 3 (RHR 369).

Fosliella farinosa (Lamx.) Howe
KUOP: Sta. 32 (RHR 366g, epiphytic on *Lobophora variegata).*

**Halymenia* sp.
TRUK: Sta. 2 (RHR 359a).

**Jania capillacea* Harvey
TRUK: Sta. 15 (RT 3443, epiphytic on *Turbinaria ornata).*

**Metagoniolithon* sp.
TRUK: Sta. 2 (RHR 359b), Sta. 21 (RT 3504), Sta. 25 (RT 3534).
Further studies are being made on this species which represents the first collection of this genus outside of Australia.

**Peyssonelia rubra* (Grev.) J. Ag.
TRUK: Sta. 2 (RHR 359a), Sta. 16 (RT 3461).

**Porolithon craspedium* (Foslie) Foslie
KUOP: Sta. 31 (RHR 365d).

Order Gigartinales

Ceratodictyon spongiosum Zanardini
TRUK: Sta. 14 (RT 3437).

Gelidiopsis intricata (Ag.) Vickers
TRUK: Sta. 9 (RT 3401).

Hypnea esperi Bory
KUOP: Sta. 32 (RHR 366e).

Order Rhodymeniales

Champia compressa Harv.
TRUK: Sta. 13 (RT 3433a, epiphytic on *Halimeda).*

Order Ceramiales

**Acanthophora spicifera* (Vahl) Boerg.
KUOP: Sta. 32 (RHR 366c), Sta. 34 (RT 3548a).

**Crouania minutissima* Yamada
TRUK: Sta. 20 (RT 3469).

**Dasyopsis pilosa* Weber van Bosse
KUOP: Sta. 32 (RHR 366f).

Herposiphonia delicatula Hollenberg
KUOP: Sta. 34 (RT 3547).

**Hypoglossum attenuatum* Gardner
TRUK: Sta. 26 (RT 3538).

Laurencia majuscula (Harv.) Lucas
TRUK: Sta. 20 (RT 3485).

**Laurencia parvipapillata* Tseng
KUOP: Sta. 34 (RT 3548b).
This species is represented by a single fragment, 1 cm long.

**Polysiphonia scopulorum* Harvey
TRUK: Sta. 20 (RT 3474).
KUOP: Sta. 28 (RHR 360g).

Tolypiocladia glomerulata (Ag.) Schmitz & Hauptfleisch
TRUK: Sta. 9 (RT 3395, epiphytic on *Halimeda discoidea).*

**Vanvoorstia* sp.
TRUK: Sta. 16 (RT 3453), Sta. 17 (RT 3463).
Preliminary examination seems to indicate that the specimens may represent a new species.

DISCUSSION

Eighty-five species of marine benthic algae are reported in this paper. Forty-one species or 48 percent of the listed species represent new records for the Truk area. These species consist of 4 Cyanophyta, 15 Chlorophyta, 7 Phaeophyta and 15 Rhodophyta. With the addition of these species, a total of 143 species are presently known from Truk. The author feels that this total represents approximately 75 to 80 percent of the algae actually present on Truk. It is of interest to note that of the 41 species reported as new records, 13 of them were found exclusively in water deeper than 7 meters. The continual use of SCUBA will no doubt increase the number of species known from Pacific islands.

One additional species is present in the collection which is not included in the present listing. This green alga seems to represent a new genus and will be reported on at a later date.

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ADDITIONAL RECORDS OF MARINE BENTHIC ALGAE FROM YAP, WESTERN CAROLINE ISLANDS

by Roy T. Tsuda and Mary S. Belk

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ADDITIONAL RECORDS OF MARINE BENTHIC ALGAE FROM YAP, WESTERN CAROLINE ISLANDS[1]

by Roy T. Tsuda[2] and Mary S. Belk[2]

INTRODUCTION

Yap (9°25'N. Lat., 138°02'E. Long.) consists of four closely grouped islands separated by narrow shallow channels. Encircling these islands is a barrier reef with seven major channels that provide water circulation to the lagoon from the outside. The air temperature ranges from 25°C in January to 28°C in September, and the rainfall ranges from 1.14 inches (2.9 cm) in January to 36.86 inches (93.6 cm) in December. Gressitt (1954) provides details on the terrestrial topography.

Past records of marine benthic algae from Yap can be found in nine papers (Reinbold, 1901; Okamura, 1904, 1916; Schmidt, 1928; Tokida, 1939; Hollenberg, 1968a, 1968b; Trono, 1968, 1969) where a total of 83 species have been listed. It is of interest to note that none of these authors have personally made any algal collections on Yap.

The purpose of this paper is to present a listing of the unreported species of marine benthic algae from Yap that the senior author collected while on an *Acanthaster planci* (crown-of-thorns starfish) survey trip during November 24 to December 1, 1970. Twenty-three species are listed in this paper, thereby increasing the total number of species known from this island group by 28 percent. A total of 106 species (8 Cyanophyta, 41 Chlorophyta, 15 Phaeophyta, and 42 Rhodophyta) are now known from Yap. It should be pointed out that these collections are reported here strictly for phytogeographic purpose. It is only through the continual collecting and reporting of additional species that a flora of a given area may one day be said to be "well-known" floristically. All specimens are cataloged in the University of Guam Herbarium.

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The authors thank Dr. Yuzuru Saito, Hokkaido University, for examining the two species of *Laurencia*.

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STATION DESCRIPTIONS

STATION 1: Seaward terrace outside barrier reef, 3 m deep, 4 km SW of Tomil Harbor entrance, XI-24-70.

2: Inner lagoon reef, *Enhalus* bed, 1 m deep, Nimpol, XI-25-70.

3: Inner lagoon reef, *Enhalus* bed, 1-2 m deep, Pelak, XI-25-70.

4: Outer lagoon reef, 1-2 m deep, Pelak, XI-25-70.

5: Outer lagoon reef, dead *Acropora* bed, 2 m deep, Tomil Harbor, XI-27-70.

6: Outer lagoon reef, 2 m deep, SW of Tomil Channel, XI-28-70.

7: Inner lagoon reef, 1-2 m deep, Garin I., XI-28-70.

8: Inner lagoon reef, *Enhalus* bed, 1-2 m deep, between Map I. and Rumung I., XI-29-70.

9: Lagoon channel, deep hole, 10-13 m deep, off USCG Beach, 2.5 km S of Gofenu Entrance, XI-29-70.

10: Outer lagoon reef, 1-2 m deep, Tomil Harbor, XI-30-70.

11: Intertidal zone at shoreline, NE of Pelak Entrance, XII-1-70.

SPECIES LISTING

DIVISION CYANOPHYTA (blue-green algae)

Order Oscillatoriales

Calothrix confervicola (Roth) Ag.
Sta. 10 (RT 4048, mixed with *Microcoleus lyngbyaceus).*

Calothrix pilosa Bornet & Flahault
Sta. 2 (RT 3969, mixed with *Microcoleus lyngbyaceus* and sand).

Hormothamnion solutum Bornet & Flahault
Sta. 2 (RT 3961b, epiphytic on *Avrainvillea erecta),* Sta. 10 (RT 4048, mixed with *Microcoleus lyngbyaceus)*

Schizothrix mexicana Gomont
Sta. 7 (RT 4003, tufts on coral), Sta. 9 (RT 4025, loose filaments on coral).

Spirulina subsalsa Gomont
Sta. 10 (RT 4048, mixed with *Microcoleus lyngbyaceus).*

DIVISION CHLOROPHYTA (green algae)

Order Ulotrichales

Enteromorpha kylinii Bliding
Sta. 5 (RT 3989)

Order Cladophorales

Chaetomorpha crassa (Ag.) Kütz.
Sta. 3 (RT 3978)

Order Siphonales

Avrainvillea lacerata Harvey
Sta. 10 (RT 4042)

Bryopsis pennata Lamx.
Sta. 1 (RT 3955b, epiphytic on *Laurencia* sp.)

Caulerpa elongata Weber van Bosse
Sta. 9 (RT 4021), Sta. 10 (RT 4041).

Halimeda gigas Taylor
Sta. 5 (RT 3984), Sta. 7 (RT 4005c), Sta. 8 (RT 4018c), Sta. 9 (RT 4022b)

Halimeda simulans Howe
Sta. 2 (RT 3968), Sta. 7 (RT 4005b).

Order Siphonocladales

Dictyosphaeria versluysii Weber van Bosse
Sta. 2 (RT 3970)

Order Dasycladales

Neomeris vanbosseae Howe
Sta. 8 (RT 4014), Sta. 11 (RT 4049)

DIVISION PHAEOPHYTA (brown algae)

Order Ectocarpales

Ectocarpus indicus Sonder
Sta. 7 (RT 4006c, epiphytic on *Padina minor).*

Order Dictyotales

Dictyota apiculata J. Ag.
Sta. 8 (RT 4013b).

Dictyota cervicornis Kütz.
Sta. 2 (RT 3959), Sta. 7 (RT 4008), Sta. 8 (RT 4013a).

Padina minor Yamada
Sta. 8 RT 4017, Sta. 11 - RT 4050.

DIVISION RHODOPHYTA (red algae)

Order Cryptonemiales

Metagoniolithon sp.

Sta. 2 (RT 3967), Sta. 6 (RT 3996).

These specimens represent the second collection of this genus from Micronesia and are presently being examined by Dr. H. William Johansen of Clark University, Massachusetts.

Order Gelidiales

Gelidium pulchellum (Turn.) Kütz.

Sta. 10 (RT 4039).

Order Ceramiales

Laurencia majuscula (Harvey) Lucas

Sta. 9 (RT 4026, identified by Dr. Y. Saito of Hokkaido University).

Laurencia sp.

Sta. 1 (RT 3955a), Sta. 3 (RT 3979), Sta 4 (RT 3982).

According to Dr. Saito, these specimens are similar externally to *L. papillosa* but lack the characteristic palisade cortical cells. This species will be described as "new" in a future paper after additional fertile specimens are examined.

Polysiphonia scopulorum Harvey

Sta. 9 (RT 4029).

DISCUSSION

The most conspicuous marine plant in the predominantly sandy inner lagoon reef is *Enhalus acoroides*, which forms a band of about 50 meters or more around the entire coast of the four islands. Various algal species, e.g., *Dictyota cervicornis, Halimeda opuntia, Halimeda macroloba* and *Caulerpa racemosa,* are found interspersed among the *Enhalus*.

Although the navigable lagoon channel which surrounds the inner reef possesses a sandy substratum with almost no algae, several larger depressions, 13 meters deep, are found east of Gagil and west of Rumung Island. The dominant algae along the coral rim of these depressions are *Caulerpa elongata, Halimeda gigas, Tydemania expeditionis* and *Rhipilia orientalis*.

The outer lagoon reef consists of patches of live corals interspersed with sand pockets and coral rubble. *Microcoleus lyngbyaceus* and *Caulerpa urvilliana* are the most conspicuous algae inhabiting the sand pockets, while *Polysiphonia scopulorum* and *Gelidiopsis intricata* cover the branches of dead *Acropora*. *Valonia ventricosa* and *Actinotrichia fragilis* are abundant among the coral rubble in this zone. However, algae are almost non-existent in the live coral areas. Likewise, the reef margin, seaward reef front and the seaward submarine terrace, possess very few algae except for crustose corallines.

The marine flora on the reefs of Yap is very limited in terms of standing crop. This situation is not at all unusual since other islands which possess live corals reveal this same condition. Although a direct correlation seems to exist between the greater diversity of fishes and a live reef, a negative correlation is present between a smaller algal number and a live reef situation. An obvious reason for a greater algal flora on dead reefs is the larger settling surface available to the algal spores and zygotes.

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ATOLL RESEARCH BULLETIN

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CARBONATE LAGOON AND BEACH SEDIMENTS OF TARAWA ATOLL, GILBERT ISLANDS

by Jon N. Weber and Peter M.J. Woodhead

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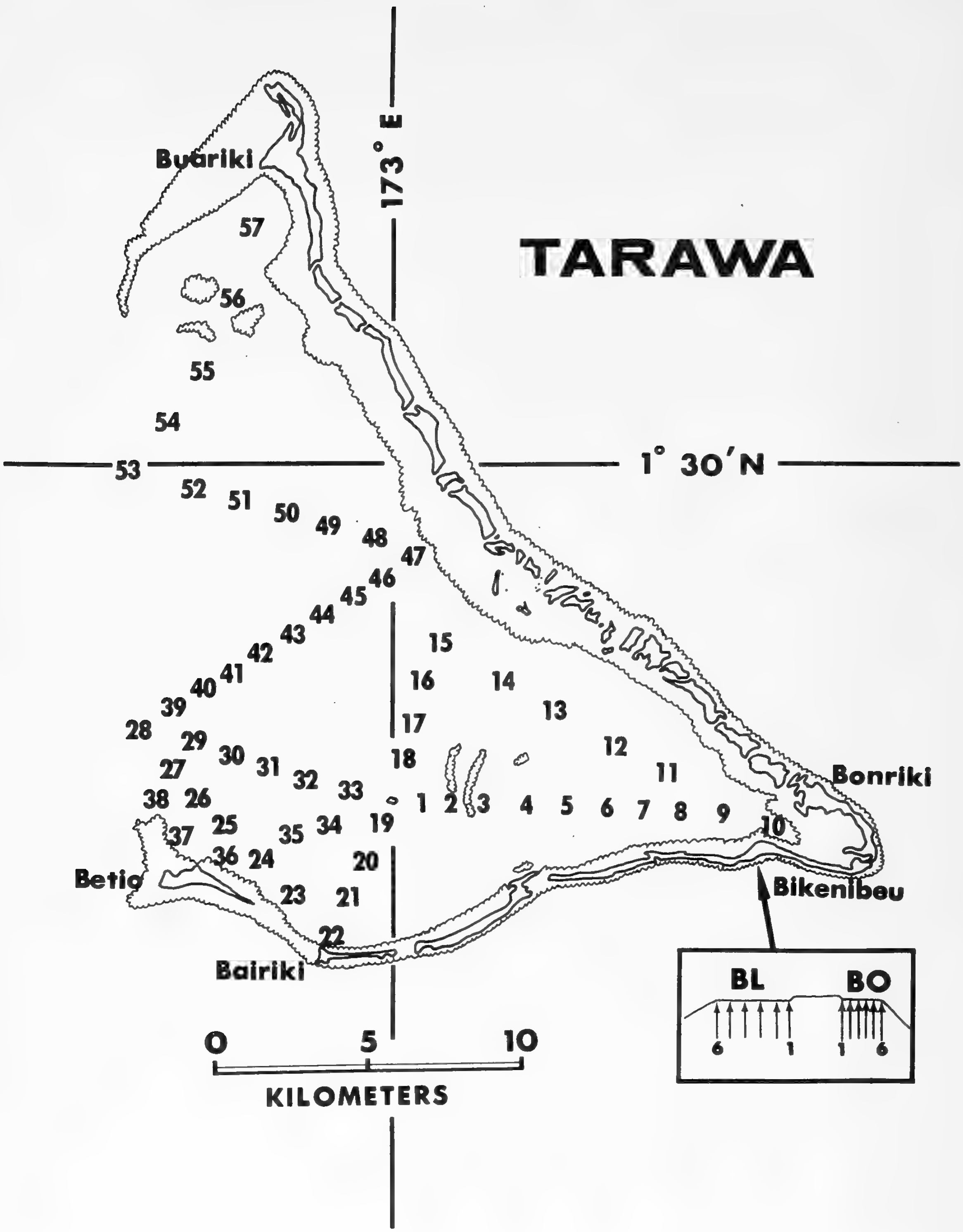

Figure 1: Locations of sampling stations in Tarawa Lagoon. Inset at lower right shows positions of fringing reef flat sediment samples on Bikenibeu Island. BL = lagoonal reef flat; BO = ocean reef flat; BL and BO sample numbers begin at shore (1) and end at reef edge (6).

CARBONATE LAGOON AND BEACH SEDIMENTS OF TARAWA ATOLL, GILBERT ISLANDS

by Jon N. Weber[1] and Peter M. J. Woodhead[2]

SUMMARY

A large, shallow lagoon, almost isolated from the open ocean, distinguishes Tarawa from other atolls where carbonate sedimentation has been investigated. Passes through the atoll reef are lacking except along the western periphery. Size distribution statistics (median grain size, coefficients of sorting and skewness) were obtained for 57 sediment samples from Tarawa Lagoon and 12 samples from the fringing reef flats. Samples were subdivided into ten separate grain size fractions and the mineralogy of each fraction was determined. Component analysis of the larger grains was undertaken to identify the different sources of carbonate particles. Lime muds are accumulating in shallow water (6-10 m) over a large area of the southeastern lagoon. Evidence provided by mineralogy, carbon isotopic composition, and electron microscopy indicates that the fines consist of a mixture of algae-secreted needles and particles derived from the physical and biological breakdown of skeletal detritus. The abundance of carbonate muds in shallow water is attributed to the absence of current winnowing.

INTRODUCTION

Tarawa possesses several features which distinguish it from other atolls where carbonate sedimentation has been studied. These features especially concern the depth of the lagoon and the relatively poor connection between it and the open ocean. The water in much of Tarawa Lagoon is murky, a fact which is readily evident from the air. At the extreme southeastern corner of the lagoon, underwater visibility is less than 2 m, and associated with the high degree of turbidity are fine-grained carbonate muds accumulating in shallow water.

The lagoon at Tarawa differs significantly from those of Bikini, Eniwetok, and other atolls where detailed sediment studies were conducted by Emery *et al.* (1954). Tarawa Lagoon is shallow, averaging about 12 to 15 m, with a maximum depth of 25 m. Rongelap, Eniwetok, and Bikini Atolls, however, have lagoons averaging about 50 m in depth (maximum 70 m). Furthermore, Tarawa Lagoon is encircled by coral reefs at sea level except along the western margin where the atoll reef top is submerged to about 9 m. There is only one deep (20-25 m) pass into Tarawa, whereas Rongelap Lagoon is connected to the sea by nine passes with a maximum depth of 66 m, and Bikini has eight passes or channels with a maximum depth of 60 m. These variations in lagoon physiography might exert considerable influence on the characteristics of sedimentary material accumulating on the atoll.

The dominant sediment contributors in most coral reef environments appear to be *Halimeda*, corals, molluscs, foraminifera, and the coralline algae. In unusual circumstances, other types of sediment may form, for example, non-skeletal carbonates in the lagoon of Hogsty Reef (Milliman, 1967) or the pelagic foraminifera, benthonic foraminifera, and mollusc sands on the Seychelles Bank (Lewis and Taylor, 1966). Considerable variations in the abundance of carbonate grains from different sources are observed from one reef to another and often within a single reef complex. *Halimeda* and foraminifera, for example, are important in the Great Barrier Reef (Maxwell, 1968) and the Florida reef tract (Ginsburg, 1956) provinces. Over large areas of the floors of Eniwetok and Bikini Lagoons, *Halimeda* is a major sediment

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component, often comprising between 75 and 100% of the total (Emery *et al.*, 1954). In Fanning Lagoon, however, foraminifera and *Halimeda* are not substantial contributors (Roy, 1970). *Halimeda* fragments are also relatively scarce in the sediments of Kure and Midway Atolls (Gross *et al.* 1969). At Pearl and Hermes Reef, carbonate of foraminiferal derivation is considerably less abundant than grains from algae, corals, and molluscs (Thorp, 1936). Thus the striking differences in the proportions of various carbonate contributors reported for Pacific islands and atolls is an additional incentive for investigating the sedimentary deposits of Tarawa.

PHYSICAL SETTING

Tarawa Atoll, part of the Gilberts Islands group, is located in the central Pacific Ocean just north of the equator (1°30'N, 173°E). The atoll is triangular in shape, with approximate dimensions of 25 km E-W and 30 km N-S. Although the dominant surface ocean current is from the east, the wind regime changes from NE Trades in Jan.-Feb. to SE Trades in July-Aug. The coral reef is continuous and rises to the surface on the windward side of the atoll, supporting numerous islands and islets no more than a few feet above sea level. These islands are surrounded by reef flats as much as 300 to 800 m wide on both lagoonal and seaward shores, and they are separated from each other by narrow channels which are generally emergent at low tide. Along the western margin of the atoll, the reef is submerged to depths of about 8 to 10 m. The main entrance to the lagoon is a breach in the leeward, submerged reef, located just north of Betio near sampling station TA-28 (Fig. 1). A strong (1-3 km/hr) current flows through this channel, its direction reversing with each change in the tide. Despite its size (400 sq. km) the lagoon is relatively shallow, with an average depth between 12 and 15 m, and a maximum depth of 25 m. Irregular topography characterizes the lagoon floor, and coral knolls or pinnacle reefs are fairly common.

METHODS

A total of 57 sediment samples ("TA-series") was collected in Tarawa Lagoon by diving or by means of a modified Van Veen bottom sampler. Additional sediment was sampled on the flats of the reefs fringing Bikenibeu Island on both the lagoon ("BL-series") and ocean ("BO-series") facing sides. The locations of sampling stations are shown in Fig. 1. Sediment samples were processed by mechanical techniques described in detail by Neumann (1965), and size distribution statistics were calculated from the resulting size-frequency distributions. Central tendency is expressed by the median grain size *(Md)* in mm. Trask sorting *(So)* and skewness *(Sk)* coefficients are used to indicate dispersion and symmetry: $So = \sqrt{Q_3/Q_1}$ and $Sk = Q_1Q_3/(Md)^2$, where Q_1 and Q_3 are the first and third quartiles of the cumulative frequency distribution. Each sample was divided into ten size fractions designated by the letters A to J in order of decreasing grain size. The limits of these size classes, in mm, are:

A	2.00 - 0.841
B	0.841 - 0.420
C	0.420 - 0.250
D	0.250 - 0.177
E	0.177 - 0.149
F	0.149 - 0.125
G	0.125 - 0.105
H	0.105 - 0.082
I	0.082 - 0.074
J	<0.074

The abundances of aragonite, high-magnesium calcite (HMC), and low-magnesium calcite (LMC) in each size fraction were determined by X-ray diffraction analysis described in detail by Weber (1968). Carbon and oxygen isotopic composition data were obtained by mass spectrometric methods described by Deines (1970). Size frequency distribution statistics for each sediment sample are given in Table 1. Mineralogical data are listed in Table 2.

SEDIMENTS OF THE LAGOON

There is a considerable difference between the material deposited in the eastern, relatively sheltered corner of the lagoon, and that covering the floor of the more exposed western portion. The sediments in the Bonriki-Bikenibeu area are essentially carbonate muds and oozes, whereas lime sands predominate elsewhere in the lagoon. In samples TA-12, 8, and 7 (Fig. 1) for example, the percentage of grains less than 0.07mm in diameter amounts to 75, 78, and 71 respectively. Coarse-grained sediments are typical of the western lagoon margin. Sample TA-28 yielded nothing finer than 0.125mm, and grains larger than 0.18mm accounted for 98% of the total. Similarly, 95% of TA-29 and 93% of TA-53 consisted of particles with diameters greater than 0.18mm. The striking change in median grain size from east to west is illustrated in Fig. 2. The fine-grained sediments in the eastern neck of the lagoon tend to be very poorly sorted ($So = 8.49$). Progressing westwards, sorting becomes increasingly better, with the Trask index decreasing to 1.58 at station TA-28.

Aragonite is the most abundant mineral component in all samples from the lagoon. Maximum and minimum amounts were found in TA-26 (92%) and TA-28 (65%), but approximately three-quarters of the sediments sampled contained between 75 and 90%. The average concentration of aragonite increases from 66% at the eastern corner of Tarawa Lagoon to about 80-88% in the center and then decreases abruptly to 65% at the western atoll reef edge (TA-28, Fig. 1). Aragonite is distributed among all ten of the size fractions studied, but in general, the intermediate grain size categories tend to have slightly higher percentages of this mineral than do the very fine or very coarse grades (Fig. 3). Changes in the distribution of aragonite as a function of grain size are shown for the east-west transect in Fig. 4, and for the TA-53 to TA-57 transect of the northern corner of the lagoon in Fig. 5.

Low-magnesium calcite is a minor constituent of the sediment throughout the lagoon. Average concentrations are generally between 2 and 8%, and with few exceptions, the mineral appears to be more or less equally distributed among the various size fractions of a given sample. Only at the western edge of the atoll reef where lagoonal and open ocean waters mix does LMC become abundant. The increase in concentration of low-magnesium calcite as the reef margin is approached is rather abrupt, as illustrated by the sample series TA-40 (9% LCM), 39 (14%) and 28 (17%). Almost all of the additional LMC in the reef edge sediments is found in a single size fraction. For example, 82, 73, and 89% of the total LMC in samples TA-40, 39, and 28 respectively occurs in the 0.42 to 0.48mm grain size range. With the exception of the western reef margin where the LMC content is variable, the distributions of high-magnesium calcite and aragonite in the lagoon sediments are complementary.

COMPONENT ANALYSIS OF LAGOON SEDIMENTS

Grains larger than 0.5mm from a number of samples on the east-west lagoon transect were identified and counted under a binocular microscope. The results for major components are summarized in Fig. 6. Constituent carbonate grains from the extreme western part of the lagoon (e.g. samples TA-28, 29, 39) are "fresh" in appearance, are not greatly abraded, and hence are relatively easily identified. Progressing eastward, however, the grains become increasingly abraded and are characterized by a "weathered" appearance. *Halimeda* fragments constitute a major component of the sediment throughout the lagoon but their abundance is greatest in the eastern part, for example, 63% of the > 0.5mm grains in sample TA-7.

The percentage of coral debris is highest in the west near the atoll reef margin. Coral fragments decline markedly in abundance towards the east, amounting to essentially zero percent at station TA-7. There is a slight increase in the quantity of coral produced grains in the lee of the seaward (eastern) atoll reef, for example at TA-9. Skeletal detritus attributed to mollusca is also a significant sediment component, and as shown in Fig. 6, this material is most abundant in the center of the lagoon.

Compared with other carbonate sediments of coral reef environments, echinoderm debris appears to be unusually common. The percentage of this component is low in the western lagoon but it steadily increases eastwards, reaching up to 20% of the > 0.5mm grains in the region where the fine carbonate muds are accumulating (e.g. TA-6, 7, 8, 9). Skeletal ossicles of the echinoid *Echinometra*, ophiuroids, and crinoids constitute the greater portion of recognizable echinodern-derived grains from samples near the western atoll reef area, whereas elsewhere in the lagoon, heart urchin debris predominates. It is noteworthy that foraminifera contribute very little sand size carbonate throughout the lagoon except in the beach areas and along the western atoll reef zone. The 0.4 to 0.8mm size fraction of beach sands is almost exclusivey composed of the foram *Calcarina*. In sample TA-28, the benthonic foraminifera constitute 25% of the 0.84 to 2.00mm and 45% of the 0.42 to 0.84mm size fractions. Most of the smaller tests are *Amphistegina*, whereas *Heterostegina* is the major contributor of the larger shells. Pelagic foraminifera were very seldom observed, even in samples from the western atoll reef margin.

Because of their fresh appearance, alcyonarian spicules are conspicuous in sediment samples from the western lagoon. They tend to concentrate in the 0.42 to 0.84mm size fraction but did not exceed 5% of any sample. Although coralline algae amounted to 9% in one sample, this component along with bryozoa, crustacean, and annelid debris, etc. are minor constituents of the > 0.5mm grains in the lagoonal sediments of Tarawa Atoll.

Major sources of aragonite are the green algae, especially *Halimeda*, the scleractinian corals, pelecypods, and gastropods. Smaller quantities of this mineral might be derived from hydrozoans, the octocoral *Heliopora*, some bryozoans, scaphopods, cephalopods, and some annelids. Producers of high-magnesium calcite include echinoderms, the coralline and red algae, benthonic foraminifera, alcyonarians, some bryozoans, calcareous sponges, decapods, and some annelids. Among the low-magnesium calcite contributors are a few benthonic foraminifera, and some pelecypods and gastropods. The foram *Amphistegina* secretes low-magnesium calcite (Fig. 7) which accounts for the unusually high percentage of LMC in sample TA-28.

COMPARISON OF SEDIMENTS ON REEF FLATS FACING OCEAN AND LAGOON

Reef flats around the islands extend both seaward and into the lagoon, usually for appreciable distances (Fig. 1). As a substantial proportion of the total sediment associated with the atoll is derived from these reefs, samples were collected from reef flat environments on each side of Bikenibeu Island for comparison with sediments deposited within the lagoon proper. Physical conditions as well as the relative abundance of carbonate contributors are significantly different on the two types of reef flat. That facing the ocean, for example, is subjected to constant, high-energy wave action. Coralline algae, regular echinoids, and corals such as *Pocillopora* and *Favites* are conspicuous on the exposed seaward reef flats, whereas irregular echinoids, *Porites*, and calcareous green algae are more abundant on the flats adjacent to the lagoon. The species composition of the molluscan fauna of the two environments is also different.

As expected, the seaward reef surfaces retain little sediment with the exception of the beach and the small localized deposits in isolated depressions. These sediments are relatively coarse grained throughout (av. median diameter 1.13; range of median diameter 0.53 to 1.80mm).

In contrast, the lagoonal reef flats are almost completely covered with carbonate sediment having an average median grain size of 0.48mm (range of median 0.32 to 0.67). In this environment, median grain size decreases slightly from the middle of the flat to the edge of the lagoon. Samples from both reef flats are generally well sorted as indicated by the low values of the Trask sorting coefficient (av. 1.8 for the lagoon flat and 2.1 for the ocean flat). At Bikenibeu, the degree of sorting increases from mid flat to lagoon edge but decreases from mid flat to ocean edge, probably reflecting the fact that the only significant sediment accumulations in the exposed, high-energy wave zone on the seaward flat are found in comparatively protected holes and depressions. Perhaps the most conspicuous difference between sediments of the lagoon and ocean sides of the island is the effect of abrasion caused by wave action. Carbonate grains on the seaward flats have a much higher degree of roundness and polish. The vitreous luster enhances the color of the component grains and imparts a distinctive appearance to the sediment.

Aragonite is the most abundant mineral in all reef flat samples (Fig. 8) and in general, the lagoonal reef flat sediments contain a higher percentage than those on the seaward flat. From Bikenibeu beach to the edge of the lagoon there is a regular increase in the aragonite content from 50 to 84%, whereas on the ocean size of the island, the percentage of aragonite tends to decrease from 65% at the shore to 45% at the reef edge. Low-magnesium calcite constitutes from 1 to 2% of the sediments on the lagoon reef flat but was seldom detected in samples collected on the seaward flat. Thus the aragonite and high-magnesium calcite distribution patterns can be considered complementary.

ORIGIN OF THE LIME MUDS

The quantitative importance of lime mud in the stratigraphic record has been emphasized by Matthews (1966) who found it paradoxical that studies of Recent carbonate sediments generally have concentrated on the genesis of the sand size particles rather than on the origin of the fine-grained constituents. In some major coral reef provinces, carbonate sands are clearly much more abundant than carbonate silts or muds. Sediments of the Capricorn reef complex of Australia, for example, seldom contain more than 2% mud (Maiklem, 1970). According to Maxwell (1968), very little fine carbonate is produced in the Great Barrier Reef system of Australia, and the mud present in sediments of that region is predominantly of terrigenous origin. Elsewhere the deficiency of fine particles and the high proportions of sand and gravel may be explained by removal of the fines into deeper water, as at Pearl and Hermes Reef (Thorp, 1936). Gross *et al.* (1969) found that particles less than 125 microns in diameter are relatively rare on Kure and Midway Atolls except in the deeper parts of the lagoons. Much of the fines apparently remains in suspension and is transported out of the lagoon, leaving behind the coarse-grained sediment in shallow water. Calcareous oozes are reported in the deepest parts of Kapingamarangi Lagoon, between 50 and 80 m, but McKee (1958) concludes that the mud is not likely derived primarily from the residue of sediments occurring in shallower water.

The situation at Fanning Island appears quite different in that fine-grained carbonates are unusually abundant. Muddy sediments in the lagoon at Fanning are reported by Roy (1970) who attributes most of the material to physical and biological abrasion or comminution of corals, molluscs, and calcareous red algae. Water in Fanning Lagoon is characterized by a high degree of turbidity, with underwater visibility often limited to 2 m or less. According to Bakus (1968) the suspended particles are generally between 5 and 15 microns in diameter. Hence the presence or absence of carbonate fines may be controlled more by the degree of current winnowing than by actual production of the grains. This is demonstrated in the case of Palmyra Atoll, at least, by the drastic changes in the lagoon following the construction of inter-island causeways in the early 1940's. Dawson (1959) reported that reef growth in the lagoon ceased after being deprived of circulating water. The lagoon became murky throughout due to the suspension of fine calcareous sediment, and inshore reef areas which once supported luxuriant

coral growth are now deeply covered with carbonate mud.

Several possible mechanisms may be important in generating carbonate fines: inorganic precipitation; algal secretion of aragonite needles; and attrition of larger calcareous skeletons by mechanical or biological processes. The first of these, inorganic precipitation, is controversial. Fine-grained sediments covering large portions of the Bahama Banks, for example, are believed to be of inorganic origin by some investigators (Cloud, 1962; Illing, 1954; Newell *et al.* 1960; Broecker and Takahashi, 1966) while others consider green algae to be the dominant source (Lowenstam and Epstein, 1957). Milliman (1967) reports that most of the lagoonal sediment at Hogsty Reef is "non-skeletal" and probably precipitated inorganically. After studying sedimentation on Serrana Bank, Milliman (1969) later postulated that non-skeletal carbonates might form in open lagoon conditions only where biogenic carbonate secretion is lacking.

Lowenstam's (1955) discovery of alga-secreted aragonite needles established an important endemic biogenic source of carbonate fines. Acicular crystals of aragonite, about 2 to 9 microns in length, are produced in large numbers by species in the Codiaceae, Dasycladaceae, Nemalionaceae, and Chaetangiaceae. Fine-grained sediments from Bermuda, Jamaica, Kayangle Atoll, Johnston Island, Guam, Ifalik, Eniwetok, and Bikini were found to contain such needles (Lowenstam and Epstein, 1957) and Lowenstam (1955) predicted that quiet water sediments in equatorial regions should carry them wherever the algae are present. Stockman *et al.*, (1967) attribute most of the lime mud in the south Florida area to the skeletal disintegration of calcareous algae.

Although experimental destruction of large invertebrate skeletons by boring organisms and abrasion tend to demonstrate the difficulty in comminuting shells to very fine particle sizes (Driscoll, 1970), it appears that physical and mechanical breakdown is an important mechanism of mud formation in some areas. Matthews (1966) described lime muds of British Honduras which contain both calcite and aragonite but are virtually devoid of aragonite needles. His analyses indicate that mechanical comminution in shoal waters and breakage of fragile mollusc and hyaline foraminifera skeletons in the lagoon are important processes in the production of these muds. Other significant mechanisms include mastication by echinoids and holothurians, and trituration of carbonates by scarid, chaetodontid, acanthurid, and pomacentrid fish (Cloud, 1952). Land (1970) reports that appreciable quantities of carbonate mud may be produced by epibiotic growth of coralline red algae and serpulid worms on the turtle grass *Thalassia.*

At Tarawa, lime muds are presently accumulating in the extreme southeastern corner of the lagoon in relatively shallow water (6-10 m). These sediments are cream to very light green in color, are extremely plastic, and poorly consolidated. The unusually soft bottom created minor sampling problems in that the sediment grab, which is triggered on contact, would not always "fire". Despite replicated sampling of this area, heart urchins *(Brissopsis* and *Maretia?)* and sand dollars *(Laganum* sp.) were the only living macrobenthos recovered. The two spatangoids were considerably more abundant than *Laganum,* and the significant concentrations of echinoderm skeletal debris in these sediments indicate that heart urchins are an important *in situ* source of carbonate (Fig. 6).

Up to 80% of the material in the eastern lagoon is found in the <0.074mm size fraction, and examination by both electron microscopy and scanning electron microscopy indicates that the bulk of the fines actually lies in the particle size range of 1 to 10 microns. Although needles, presumably aragonite (Fig. 9) are not uncommon, electron photomicrographs show a variety of grain shapes including fragments of laths and needles, platy and tabular forms, and nondescript particles. Between 60 and 75% of the carbonate and mud consists of aragonite. Low-magnesium calcite amounts to 4-8%, and high-magnesium calcite accounts for the remainder.

In much of Tarawa Lagoon, the water is turbid, and this is especially true in the region of lime mud accumulation where underwater visibility is limited to a few feet. The abundance of carbonate fines, the shallowness of the water, and the high degree of turbidity suggest the possibility of inorganic precipitation, although like the "whitings" in the Bahamas (Broecker and Takahashi, 1966), the turbidity is probably due to the suspension and resuspension of previously formed carbonate rather than *in situ* precipitation by inorganic mechanisms. Nevertheless, carbon and oxygen stable isotope ratio data were obtained to examine this possibility.

The isotopic composition of the "J" size fraction ($<$0.078mm) was determined for four samples in the area of lime mud deposition. $\delta\,13_C$ and $\delta\,18_O$ values, with respect to the PDB CO_2 standard,* are:

	$\delta 13_C$ ‰	$\delta 18_O$ ‰
TA-8	+ 1.95	- 2.53
TA-9	+ 1.70	- 2.77
TA-10	+ 1.86	- 2.55
TA-12	+ 1.53	- 2.79

Admittedly the J size fraction is a mixture of aragonite, HMC, and LMC, each of which may have a different isotopic composition. A plot of $\delta 13_C$ and $\delta 18_O$ *vs.* mineralogy, however, indicated no correlation. The average $\delta 18_O$ for the four lime muds in -2.66 ‰, which corresponds to a crystallization temperature of 28.9° C using the "paleotemperature" equation of Epstein *et al.* (1953) and assuming precipitation of the carbonate in oxygen isotopic equilibrium. The 18_O content of the ambient seawater also enters into this equation, and since this was not determined, specimens of calcareous coelenterates which precipitate skeletal $CaCO_3$ in apparent oxygen isotopic equilibrium with surrounding seawater (Weber and Woodhead, 1970) were analyzed: *Millepora* (N = 16), *Tubipora* (5), and *Heliopora* (13). The average $\delta 18_O$ of these 34 specimens is -2.29 (standard deviation 0.17 ‰) which corresponds to a calculated crystallization temperature of 27.1°C. The mean annual temperature of surface seawater at Tarawa, as obtained from monthly temperature distribution maps of the central Pacific, is 28.1°C.

While the oxygen isotope ratios are similar to those predicted for inorganically precipitated carbonate, $\delta 13_C$ data for the lime muds are several permil lower than the theoretical values, and are in the range of carbon isotopic compositions typical of biogenic carbonates. The presence of HMC and LMC in addition to aragonite further suggests that the lime muds in Tarawa Lagoon are derived from the breakdown of skeletal detritus. It is noteworthy that while the occurrence of aragonite needles is indicated by electron microscopy, numerous other grain shapes are also evident. It appears likely that the fines are a mixture of algal needles and particles produced by attrition of larger skeletal debris. On atolls, fine-grained carbonate is generally found to be accumulating only in the deepest portions of the lagoon, e.g. between 50 and 80 m at Kapingamarangi (McKee *et al.* 1959). According to McKee *et al.* a "shallow-water environment favorable for such fine-grained deposits has not been reported from any of the Pacific atolls". Tarawa, however, has extensive deposits of carbonate mud which are accumulating in shallow water. This can be attributed to protection of the sediment from current winnowing, which in turn results from the near absence of deep channels connecting lagoon and ocean, and the windbreak provided by the reef islands.

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*Using the well known δ notation, where:

$$\delta C^{13} = \left(\frac{C^{13}/C^{12}_{\text{sample}} - C^{13}/C^{12}_{\text{standard}}}{C^{13}/C^{12}_{\text{standard}}}\right)1000$$

in per mil, relative to the PDB standard CO_2.

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TABLE 1: SIZE DISTRIBUTION STATISTICS

Sample	Depth(m)	Md	So	Sk
TA - 1	13	0.45	1.94	0.94
2	12.5	0.33	2.64	0.84
3	12.5	0.34	2.05	0.82
4	16	0.13	2.98	1.06
5	14	0.17	2.01	1.24
6	14.5	0.062	2.45	0.62
7	10	0.028	4.14	1.40
8	9	0.009	8.49	0.89
9	6	0.080	2.07	1.68
10	5	0.090	1.29	0.74
11	7	0.12	1.79	1.08
12	9.5	0.010	3.16	6.40
13	10	0.19	1.92	0.98
14	8	0.20	2.15	1.15
15	10	0.27	2.95	1.01
16	18.5	0.30	2.15	0.87
17	21	0.22	2.17	0.97
18	16	0.23	1.95	0.87
19	11.5	0.35	1.95	1.12
20	8	0.46	2.01	1.01
21	9.5	0.22	2.70	0.92
22	0.	2.10	1.55	0.85
23	6.5	0.63	2.03	0.88
24	8.5	0.53	2.14	0.72
25	20.5	0.37	2.45	0.82

table 1 (continued)

TA- 26	8	0.63	1.80	1.12
27	8	0.71	1.54	0.92
28	9.5	0.90	1.58	1.11
29	8	0.87	1.70	0.96
30	13	0.80	1.79	0.89
31	10.5	0.63	1.73	0.98
32	21.5	0.50	1.46	1.09
33	9	0.56	2.27	0.84
34	22.5	0.16	1.76	1.38
35	15.5	0.53	2.52	0.90
36	10	0.36	2.60	0.69
37	10	0.35	2.50	0.86
38	5	1.20	2.07	1.18
39	10.5	0.72	2.05	0.78
40	18.5	0.68	1.83	0.78
42	19.5	0.73	2.45	0.70
43	18.5	0.30	2.83	1.08
44	13	0.76	1.89	0.95
45	12.5	0.46	2.75	0.97
46	7	0.22	2.45	1.31
47	8	0.24	2.84	0.75
48	6	0.63	2.08	0.91
49	12.5	0.39	2.95	0.76
50	12	0.57	1.88	0.74
51	19	0.70	1.84	0.71
52	17	0.35	2.67	0.99
53	6	0.82	1.62	1.05

table 1 (continued)

TA- 54	5.5	0.52	1.82	1.03
55	4.5	0.53	1.63	1.29
56	4	0.63	2.10	0.87
57	1.5	0.22	2.77	1.17
BL- 1		0.40	1.82	1.09
2		0.47	1.88	1.00
3		0.57	2.06	0.96
4		0.67	1.93	0.70
5		0.42	1.73	1.15
6		0.32	1.31	1.05
BO- 1		0.84	1.35	0.99
2		1.00	1.83	1.08
3		1.40	-	-
4		0.53	1.69	1.45
5		1.80	2.50	0.60
6		1.48	2.98	0.53

All TA samples are from Tarawa Lagoon except TA-22 which is beach sediment from Bairiki Island. BL = lagoonal reef flat at Bikenibeu Is.; BO = ocean reef flat at Bikenibeu Is.; Md = median diameter in mm; So = Trask sorting coefficient; Sk = Trask coefficient of skewness.

TABLE 2: MINERALOGICAL COMPOSITION OF SIZE FRACTIONS *

		A	B	C	D	E	F	G	H	I	J	Av.
TA-1	A	87	89	86	83	86	83	80	78	77	68	85
	HMC	10	9	12	15	13	14	17	20	19	28	13
	LMC	3	2	2	2	1	3	3	2	4	4	2
TA-2	A	88	89	90	91	88	86	88	81	78	79	87
	HMC	9	7	7	7	9	11	9	14	17	17	10
	LMC	3	4	3	2	3	3	3	5	5	4	3
TA-3	A	89	89	89	88	91	86	86	84	79	78	87
	HMC	7	7	8	9	7	12	11	12	16	18	10
	LMC	4	4	3	3	2	2	3	4	5	4	3
TA-4	A	84	87	90	90	89	88	82	82	76	76	83
	HMC	13	9	7	8	8	8	14	15	18	18	13
	LMC	3	4	3	2	3	4	4	3	6	6	4
TA-5	A	83	89	86	94	91	83	87	82	83	75	85
	HMC	14	7	10	4	6	13	9	14	13	19	11
	LMC	3	4	4	2	3	4	4	4	4	6	4
TA-6	A	76	76	76	88	95	96	94	86	76	73	77
	HMC	20	8	5	9	4	3	5	10	16	19	15
	LMC	4	16	19	3	1	1	1	4	8	8	8
TA-7	A	73	69	87	77	83	84	84	77	75	70	72
	HMC	25	25	9	17	14	11	11	17	19	23	22
	LMC	2	6	4	6	3	5	5	6	6	7	6
TA-8	A	73	71	72	78	74	85	-	-	-	64	66
	HMC	20	24	23	17	25	11	-	-	-	29	27
	LMC	7	5	5	5	1	4	-	-	-	7	7

table 2 (continued)

TA-9	A	79	79	84	84	83	81	76	72	68	63	71
	HMC	16	15	13	14	14	18	19	24	28	32	25
	LMC	5	6	3	2	3	1	5	4	4	5	4
TA-10	A	66	74	78	79	68	62	62	65	58	67	66
	HMC	33	23	19	20	31	37	37	34	39	29	31
	LMC	1	3	3	1	1	1	1	1	3	4	3
TA-11	A	80	83	85	84	83	75	78	76	74	74	78
	HMC	17	14	13	13	14	21	19	19	20	21	18
	LMC	3	3	2	3	3	4	3	5	6	5	4
TA-12	A	84	85	93	85	88	83	77	74	73	71	75
	HMC	13	10	6	12	9	13	19	22	22	22	19
	LMC	3	5	1	3	3	4	4	4	5	7	6
TA-13	A	83	89	92	93	89	87	88	78	81	78	87
	HMC	15	9	7	6	9	11	10	16	16	19	11
	LMC	2	2	1	1	2	2	2	6	3	3	2
TA-14	A	81	84	88	84	81	79	78	71	72	70	79
	HMC	18	13	11	15	17	19	19	24	24	26	18
	LMC	1	3	1	1	2	2	3	5	4	4	3
TA-15	A	75	73	82	81	78	74	73	72	70	75	76
	HMC	24	22	16	18	19	23	26	24	24	21	21
	LMC	1	5	2	1	3	3	1	4	6	4	3
TA-16	A	89	84	89	89	85	81	80	79	82	77	85
	HMC	9	13	9	9	12	15	17	16	17	18	12
	LMC	2	3	2	2	3	4	3	5	1	5	3

table 2 (continued)

TA-17	A	86	86	84	83	82	75	78	72	75	69	79
	HMC	11	11	13	13	14	18	17	23	18	24	16
	LMC	3	3	3	4	4	7	5	5	7	7	5
TA-18	A	84	88	88	88	86	83	79	76	74	77	84
	HMC	14	9	9	10	11	16	20	19	24	18	13
	LMC	2	3	3	2	3	1	1	5	2	5	3
TA-19	A	83	80	90	85	81	82	82	76	81	77	83
	HMC	14	18	8	12	16	16	17	20	15	18	14
	LMC	3	2	2	3	3	2	1	4	4	5	3
TA-20	A	86	88	90	87	89	85	82	84	81	81	87
	HMC	9	10	8	11	10	12	16	13	16	14	10
	LMC	5	2	2	2	1	3	2	3	3	5	3
TA-21	A	76	80	89	85	71	77	77	80	79	80	81
	HMC	23	16	10	13	27	19	21	17	17	16	16
	LMC	1	4	1	2	2	4	2	3	4	4	3
TA-22	A	19	11	31	34	31	27	35	44	57	50	18
	HMC	81	89	69	66	69	72	63	56	43	49	82
	LMC	0	0	0	0	0	1	2	0	0	1	0
TA-23	A	80	82	89	89	85	83	84	85	79	82	84
	HMC	17	16	9	9	13	15	14	13	17	13	14
	LMC	3	2	2	2	2	2	2	2	4	5	2
TA-24	A	71	89	92	90	87	85	82	83	79	76	86
	HMC	27	9	7	9	11	14	15	14	16	20	12
	LMC	2	2	1	1	2	1	3	3	5	4	2

table 2 (continued)

TA-25	A	75	72	83	81	76	78	78	75	75	77	77
	HMC	24	19	14	15	19	18	18	20	20	19	18
	LMC	1	9	3	4	5	4	4	5	5	4	5
TA-26	A	92	90	94	94	93	89	81	90	89	81	92
	HMC	7	9	5	5	6	10	18	9	9	16	7
	LMC	1	1	1	1	1	1	1	1	2	3	1
TA-27	A	74	80	84	88	90	91	90	-	-	-	82
	HMC	23	17	14	11	9	8	9	-	-	-	16
	LMC	3	3	2	1	1	1	1	-	-	-	2
TA-28	A	66	56	78	84	86	82	-	-	-	-	65
	HMC	32	13	16	13	11	14	-	-	-	-	18
	LMC	2	31	6	3	3	4	-	-	-	-	17
TA-29	A	78	78	83	89	92	91	88	87	82	77	81
	HMC	20	15	13	9	7	7	10	11	14	19	15
	LMC	2	7	4	2	1	2	2	2	4	4	4
TA-30	A	83	89	91	91	89	87	88	86	84	72	88
	HMC	14	9	7	8	10	11	11	12	13	22	10
	LMC	3	2	2	1	1	2	1	2	3	6	2
TA-31	A	79	82	91	88	92	88	89	86	82	76	86
	HMC	17	12	8	10	6	9	9	13	14	18	11
	LMC	4	6	1	2	2	3	2	1	4	6	3
TA-32	A	77	72	81	75	73	70	70	78	79	80	76
	HMC	18	22	15	19	20	24	25	17	16	16	19
	LMC	5	6	4	6	7	6	5	5	5	4	5

table 2 (continued)

TA-33	A	88	88	90	92	84	82	77	77	77	62	86
	HMC	9	9	8	6	12	14	19	19	19	33	11
	LMC	3	3	2	2	4	4	4	4	4	5	3
TA-34	A	82	76	85	79	74	76	72	74	77	81	77
	HMC	16	19	12	17	20	20	22	21	18	12	18
	LMC	2	5	3	4	6	4	6	5	5	7	5
TA-35	A	91	90	88	85	82	73	79	77	64	73	86
	HMC	7	8	10	12	15	24	17	17	30	22	11
	LMC	2	2	2	3	3	3	4	6	6	5	3
TA-36	A	88	85	84	85	83	79	77	75	75	74	82
	HMC	10	12	14	13	14	18	20	22	22	23	15
	LMC	2	3	2	2	3	3	3	3	3	3	3
TA-37	A	87	84	88	88	86	83	79	80	76	76	84
	HMC	11	11	9	11	12	15	19	18	21	20	13
	LMC	2	5	3	1	2	2	2	2	3	4	3
TA-38	A	87	89	98	98	94	92	91	89	83	82	90
	HMC	12	10	2	2	6	8	8	10	14	11	9
	LMC	1	1	0	0	0	0	1	1	3	2	1
TA-39	A	59	55	74	84	87	90	85	-	-	-	66
	HMC	34	16	19	12	10	8	13	-	-	-	20
	LMC	7	29	7	4	3	2	2	-	-	-	14
TA-40	A	79	57	85	88	83	84	84	85	84	74	73
	HMC	18	25	12	10	14	13	12	12	12	20	18
	LMC	3	18	3	2	3	3	4	3	4	6	9

table 2 (continued)

TA-42	A	89	79	83	83	77	73	70	68	78	78	82
	HMC	10	16	14	13	18	21	24	25	17	18	15
	LMC	1	5	3	4	5	6	6	7	5	4	3
TA-43	A	88	81	79	81	76	71	73	69	75	68	77
	HMC	11	16	15	15	19	23	25	25	22	27	19
	LMC	1	3	6	4	5	6	2	6	3	5	4
TA-44	A	89	79	88	89	82	83	81	77	80	83	84
	HMC	7	17	9	9	15	15	16	18	16	13	12
	LMC	4	4	3	2	3	2	3	5	4	4	4
TA-45	A	89	83	82	79	80	75	76	75	77	76	82
	HMC	9	13	15	17	16	22	20	21	18	18	15
	LMC	2	4	3	4	4	3	4	4	5	6	3
TA-46	A	84	84	83	82	75	75	77	76	78	73	79
	HMC	12	13	11	15	20	23	20	20	21	23	17
	LMC	4	3	6	3	5	2	3	4	1	4	4
TA-47	A	80	78	81	83	78	76	75	72	72	75	78
	HMC	17	20	17	15	20	21	22	27	24	21	20
	LMC	3	2	2	2	2	3	3	1	4	4	2
TA-48	A	85	90	92	93	91	91	90	85	83	71	89
	HMC	8	7	6	5	7	7	8	12	14	23	7
	LMC	7	3	2	2	2	2	2	3	3	6	4
TA-49	A	87	84	84	84	83	79	78	77	77	78	83
	HMC	10	13	12	13	14	17	18	21	18	18	14
	LMC	3	3	4	3	3	4	4	2	5	4	3

table 2 (continued)

TA-50	A	88	79	87	84	79	75	75	75	74	73	81
	HMC	10	18	12	14	18	22	22	22	23	21	16
	LMC	2	3	1	2	3	3	3	3	3	6	3
TA-51	A	89	80	88	86	85	81	79	78	75	79	83
	HMC	9	17	10	12	13	17	18	18	21	18	14
	LMC	2	3	2	2	2	2	3	4	4	3	3
TA-52	A	69	84	87	88	87	83	79	77	77	79	82
	HMC	26	14	11	11	12	14	18	22	20	19	16
	LMC	5	2	2	1	1	3	3	1	3	2	2
TA-53	A	86	83	92	91	84	83	81	76	79	73	86
	HMC	13	15	7	9	15	17	19	24	19	24	13
	LMC	1	2	1	0	1	0	0	0	2	3	1
TA-54	A	84	76	91	89	84	84	80	79	85	79	84
	HMC	14	19	8	10	16	16	18	21	13	18	14
	LMC	2	5	1	1	0	0	2	0	2	3	2
TA-55	A	85	67	77	74	83	79	79	76	78	75	75
	HMC	13	33	21	24	16	19	20	21	20	21	24
	LMC	2	0	2	2	1	2	1	3	2	4	1
TA-56	A	75	71	81	81	79	75	73	71	72	66	75
	HMC	24	27	19	17	19	23	26	28	26	29	23
	LMC	1	2	0	2	2	2	1	1	2	5	2
TA-57	A	68	68	75	76	72	67	66	58	60	70	70
	HMC	31	29	24	22	27	31	33	39	37	27	28
	LMC	1	3	1	2	1	2	1	3	3	3	2

table 2 (continued)

BL-1	A	29	46	53	55	53	60	61	64	68	60	50
	HMC	70	53	47	44	46	39	38	35	31	38	49
	LMC	1	1	0	1	1	1	1	1	1	2	1
BL-2	A	49	54	63	55	63	64	61	64	67	66	58
	HMC	48	46	35	45	36	35	36	35	31	32	41
	LMC	3	0	2	0	1	1	3	1	2	2	1
BL-3	A	41	56	64	59	57	61	63	66	68	69	56
	HMC	57	43	36	41	42	37	36	34	32	31	43
	LMC	2	1	0	0	1	2	1	0	0	0	1
BL-4	A	50	64	72	71	70	69	73	76	69	71	65
	HMC	49	32	27	28	29	31	26	23	30	27	33
	LMC	1	4	1	1	1	0	1	1	1	2	2
BL-5	A	60	62	80	77	80	83	83	81	79	79	73
	HMC	39	34	19	22	19	17	16	19	20	18	25
	LMC	1	4	1	1	1	0	1	0	1	3	2
BL-6	A	71	75	80	86	93	95	96	94	87	83	84
	HMC	20	22	19	14	7	5	4	6	12	13	15
	LMC	9	3	1	0	0	0	0	0	1	4	1
BO-1	A	66	64	65	71	75	81	-	-	-	-	65
	HMC	34	36	35	29	25	19	-	-	-	-	35
	LMC	0	0	0	0	0	0	-	-	-	-	0
BO-2	A	56	48	26	46	61	72	71	-	-	-	47
	HMC	44	52	74	54	39	28	29	-	-	-	53
	LMC	0	0	0	0	0	0	0	-	-	-	0

table 2 (continued)

BO-3	A	55	14	10	21	39	67	71	60	-	-	53
	HMC	45	86	90	79	61	33	29	40	-	-	47
	LMC	0	0	0	0	0	0	0	0	-	-	0
BO-4	A	40	33	31	55	62	63	63	59	62	55	37
	HMC	60	67	69	45	37	36	37	41	37	45	63
	LMC	0	0	0	0	1	1	0	0	1	0	0
BO-5	A	33	43	30	51	57	60	59	50	52	48	37
	HMC	67	57	70	49	43	39	40	50	48	51	63
	LMC	0	0	0	0	0	1	1	0	0	0	1
BO-6	A	51	46	25	41	54	61	56	55	-	-	45
	HMC	49	54	75	59	46	39	44	45	-	-	55
	LMC	0	0	0	0	0	0	0	0	-	-	0

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* mm range of size fractions specified in text. A = aragonite; HMC = high-magnesium calcite; LMC = low-magnesium calcite.

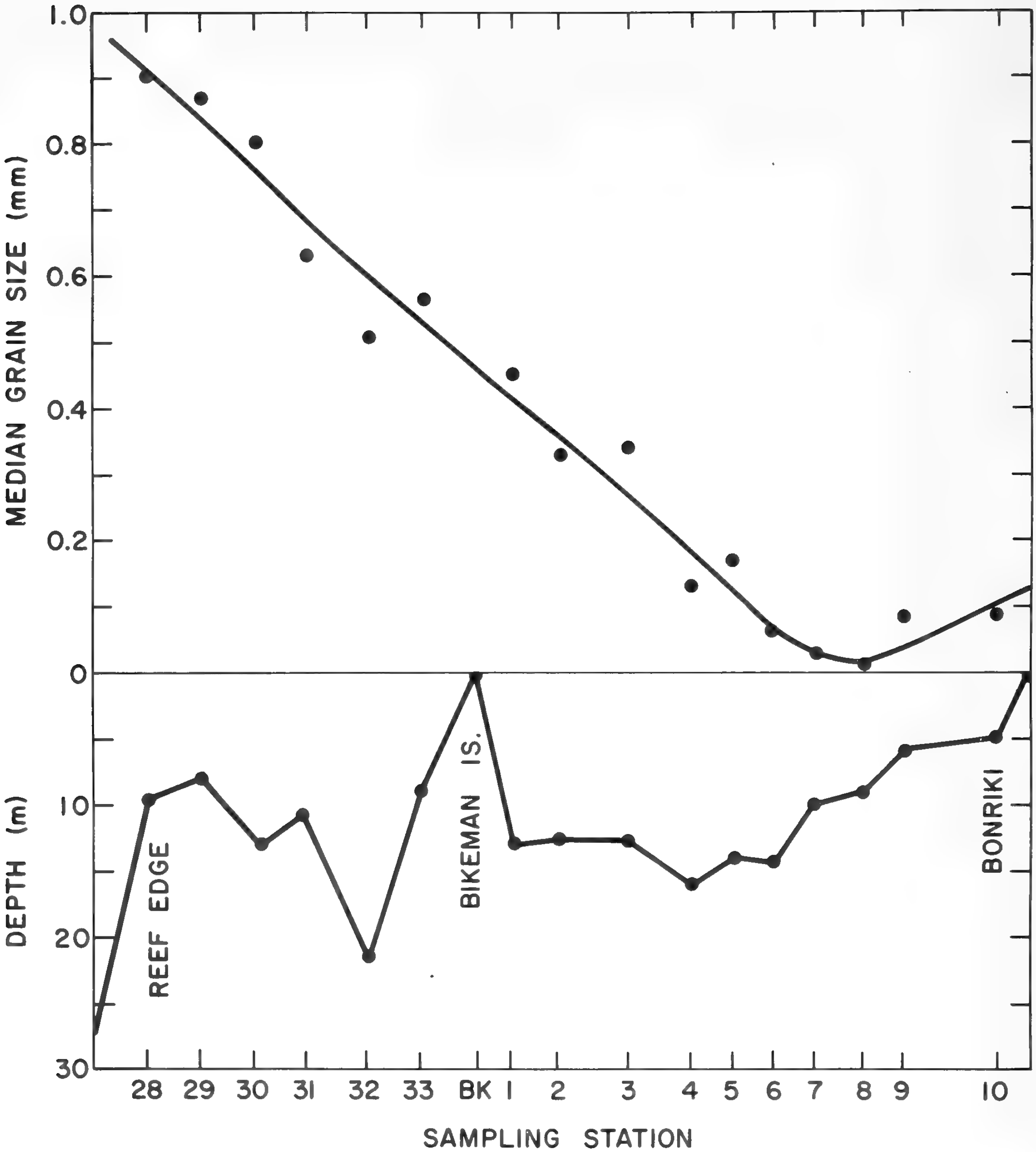

Figure 2: Median grain size of lagoonal sediments along the sampling traverse from Bonriki (eastern lagoon) to the western reef margin. Location of sampling stations given in Fig. 1.

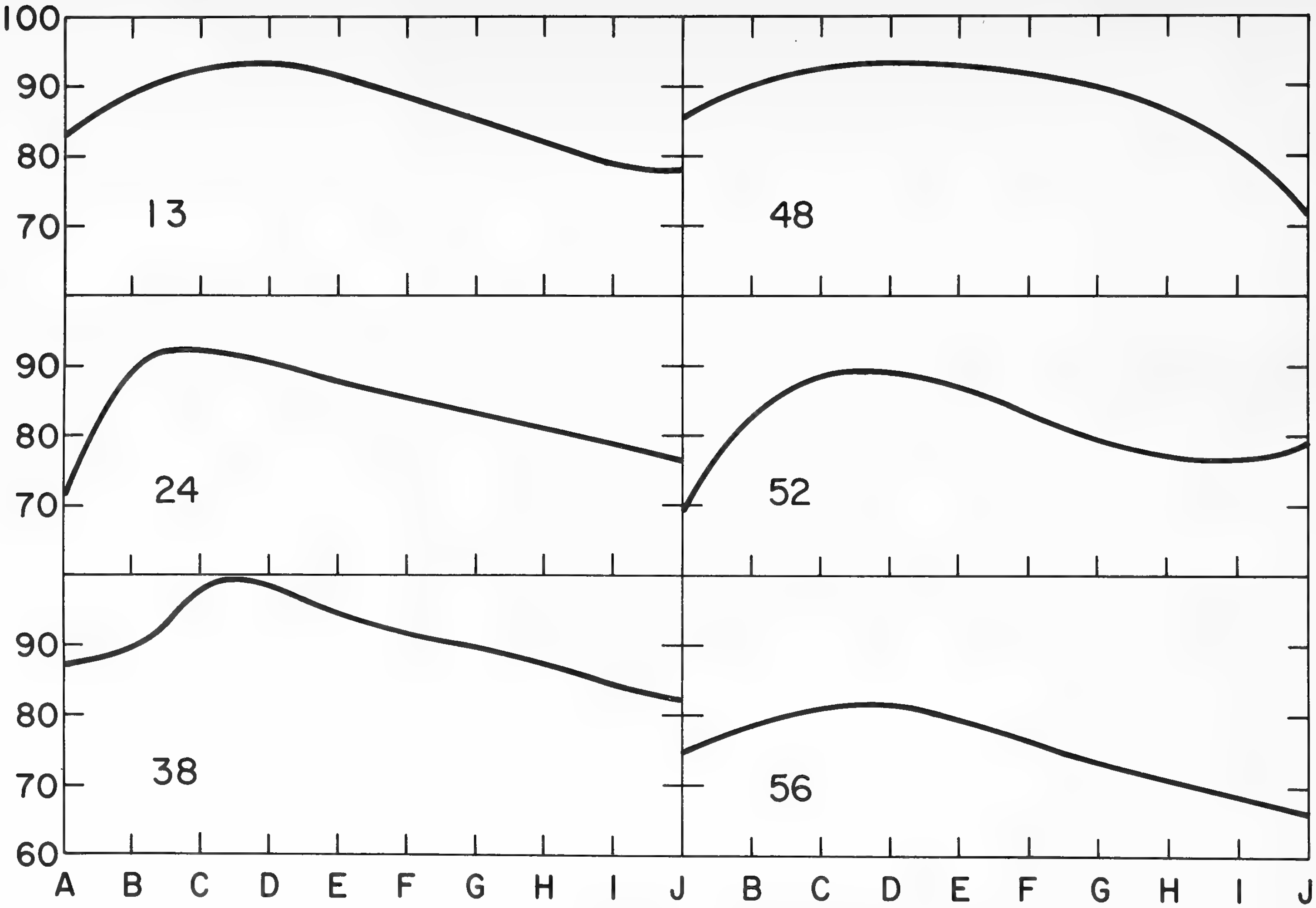

Figure 3: Mineralogical composition as a function of grain size for typical samples (number below curve corresponds to sampling station shown in Fig. 1). Curves represent the percentage of each grain size category that is aragonite. Grain size ranges corresponding to classes A and J are specified in text.

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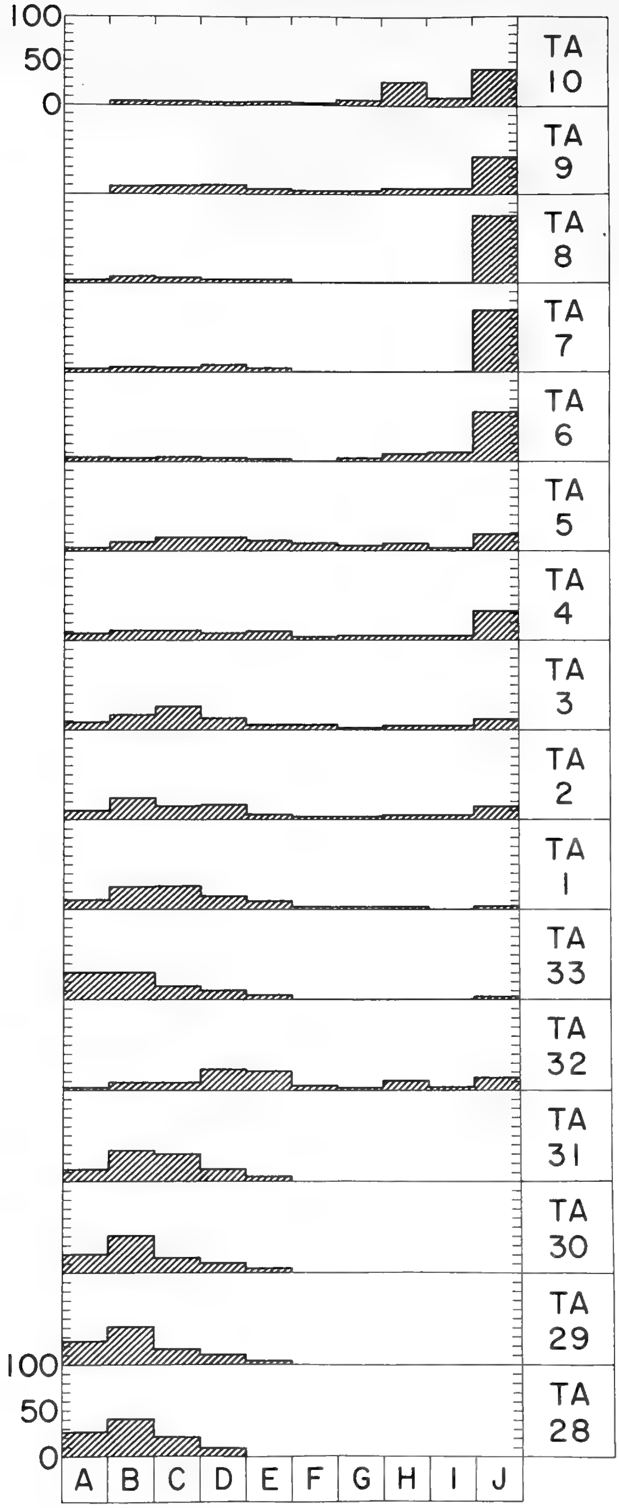

Figure 4: Distribution of total sample aragonite among grain size classes for sediment samples along the TA-10 (eastern lagoon) to TA-28 (western lagoonal reef margin) transect. The height of a column in a histogram indicates the percentage of the total sample aragonite that is in the grain size range designated by the corresponding alphabetic character (millimeter equivalents specified in text).

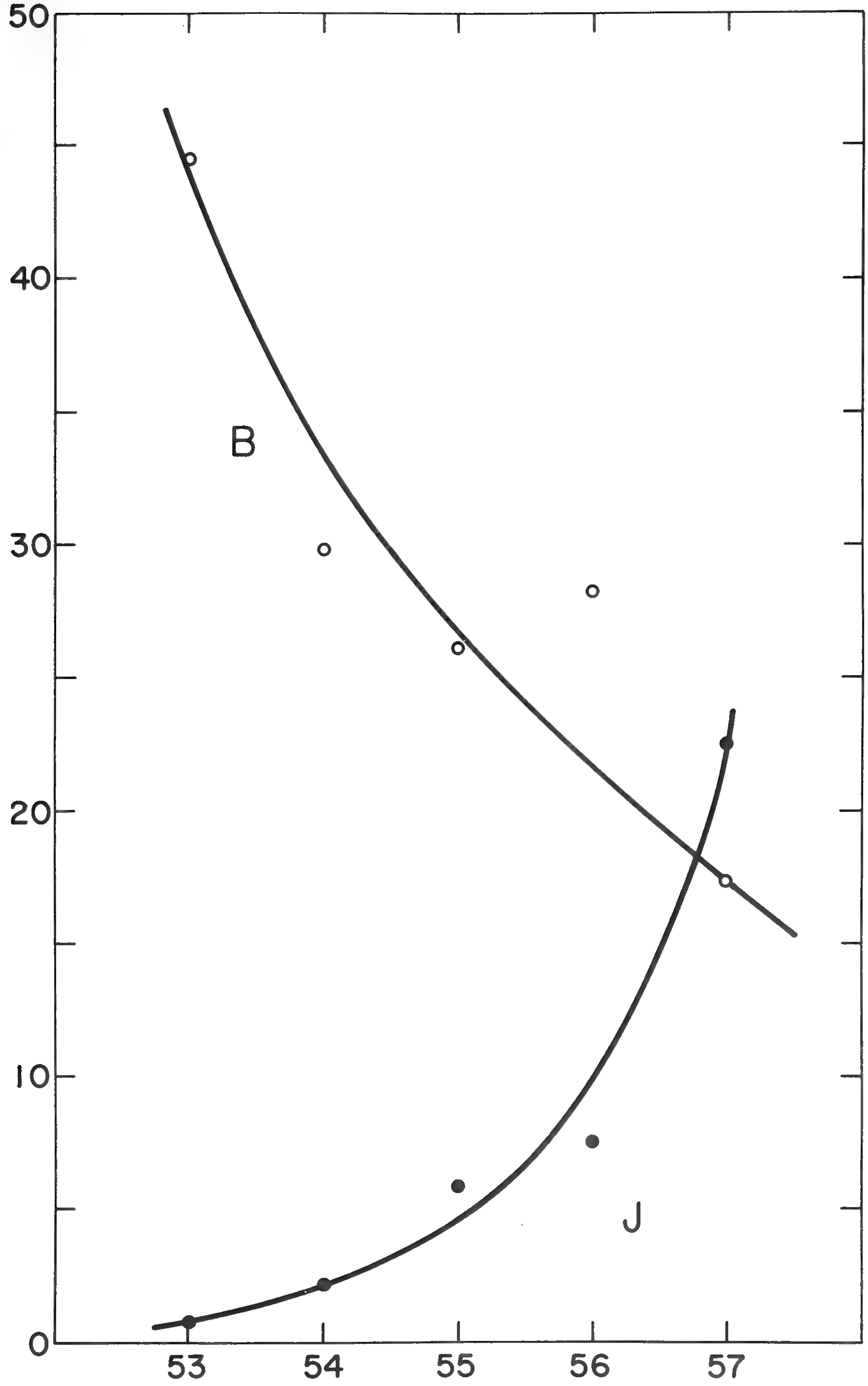

Figure 5: Systematic changes in the distribution of aragonite among grain size classes for sediments along the TA-53 to TA-57 transect in the northern corner of the lagoon (locations in Fig. 1). Curves B and J indicate the percentage of total sample aragonite that is in grain size classes B (coarse) and J (fine) respectively.

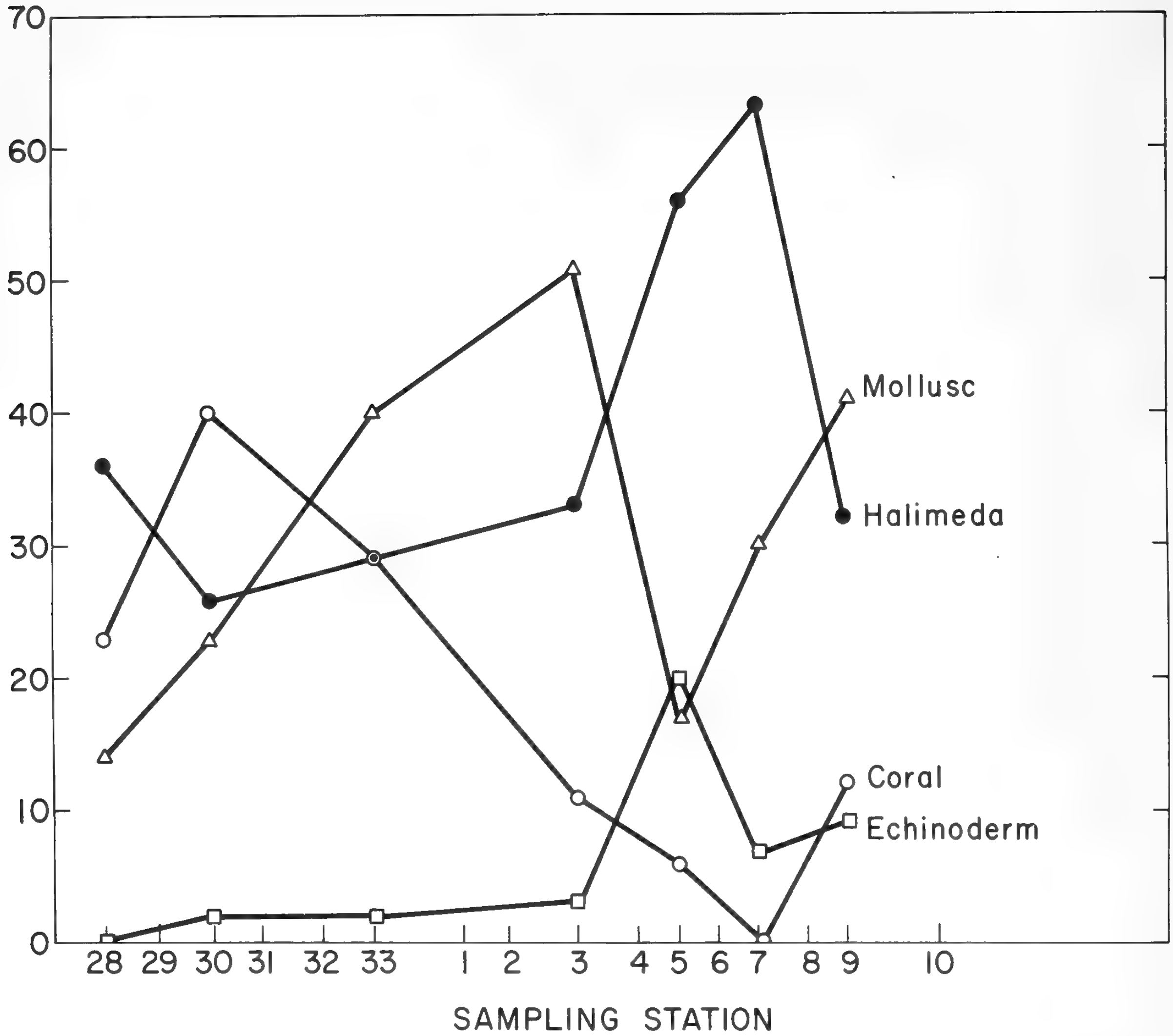

Figure 6: Percentage of four major components (>0.5mm grains) of the sediments in Tarawa Lagoon. Geographic locations of the sampling stations are shown in Fig. 1.

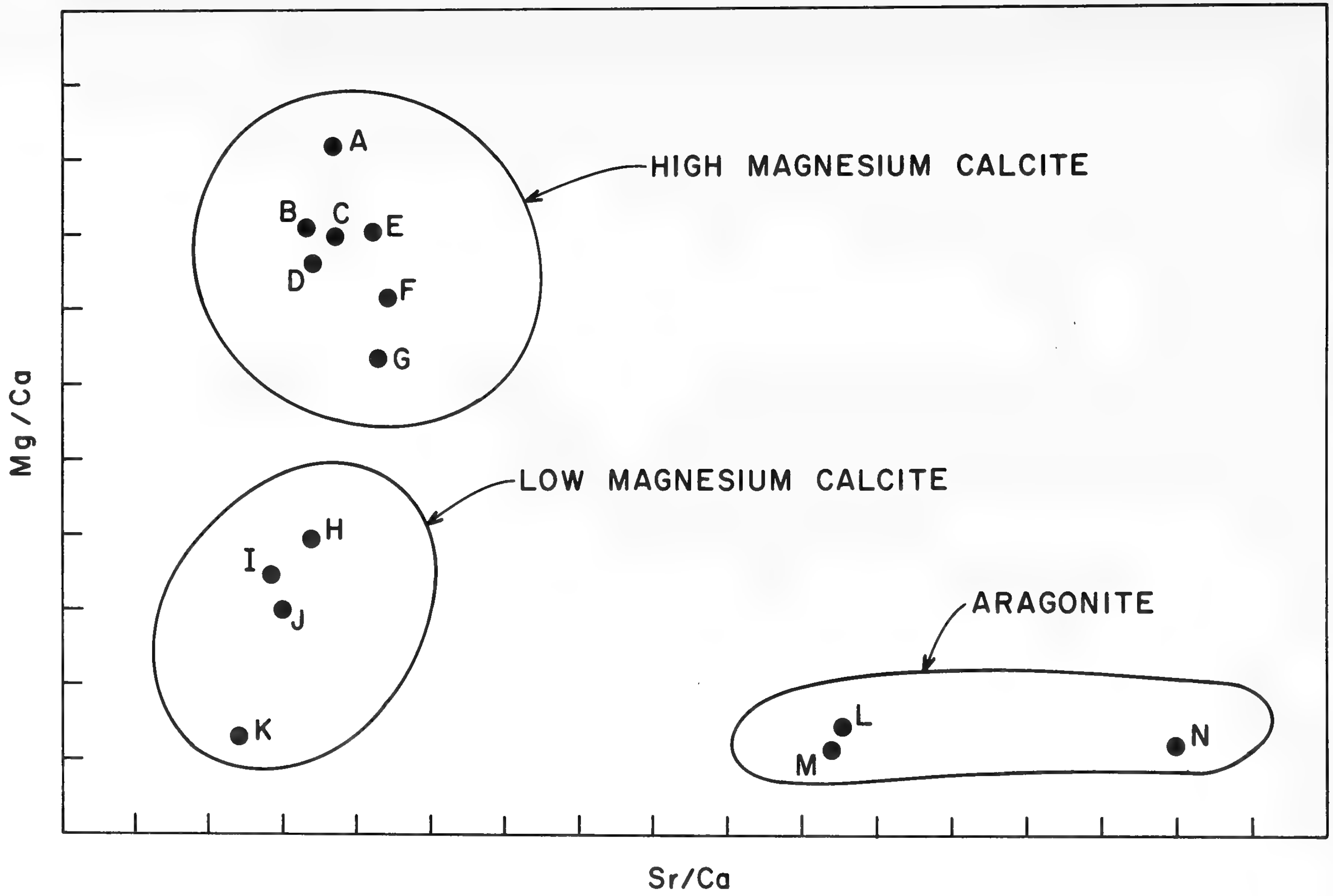

Figure 7: Mineralogy of sediment components determined by simultaneous analysis of Mg, Sr, and Ca by electron microprobe. - A (crinoid and ophiuroid ossicles), B *(Marginopora)*, C *(Calcarina)*, D (alcyonarian spicules), E *(Heterostegina)*, F *(Calcarina)*, G (echinoid coronal plates), H (echinoid spines, *Echinometra)*, I *(Amphistegina)*, J *(Amphistegina)*, K (mollusc fragment), L *(Halimeda)*, M *(Halimeda)*, N (coral debris). Mollusc and annelid detritus showed variable Mg/Ca and Sr/Ca ratios within single grains. All particles were extracted from sample TA-28.

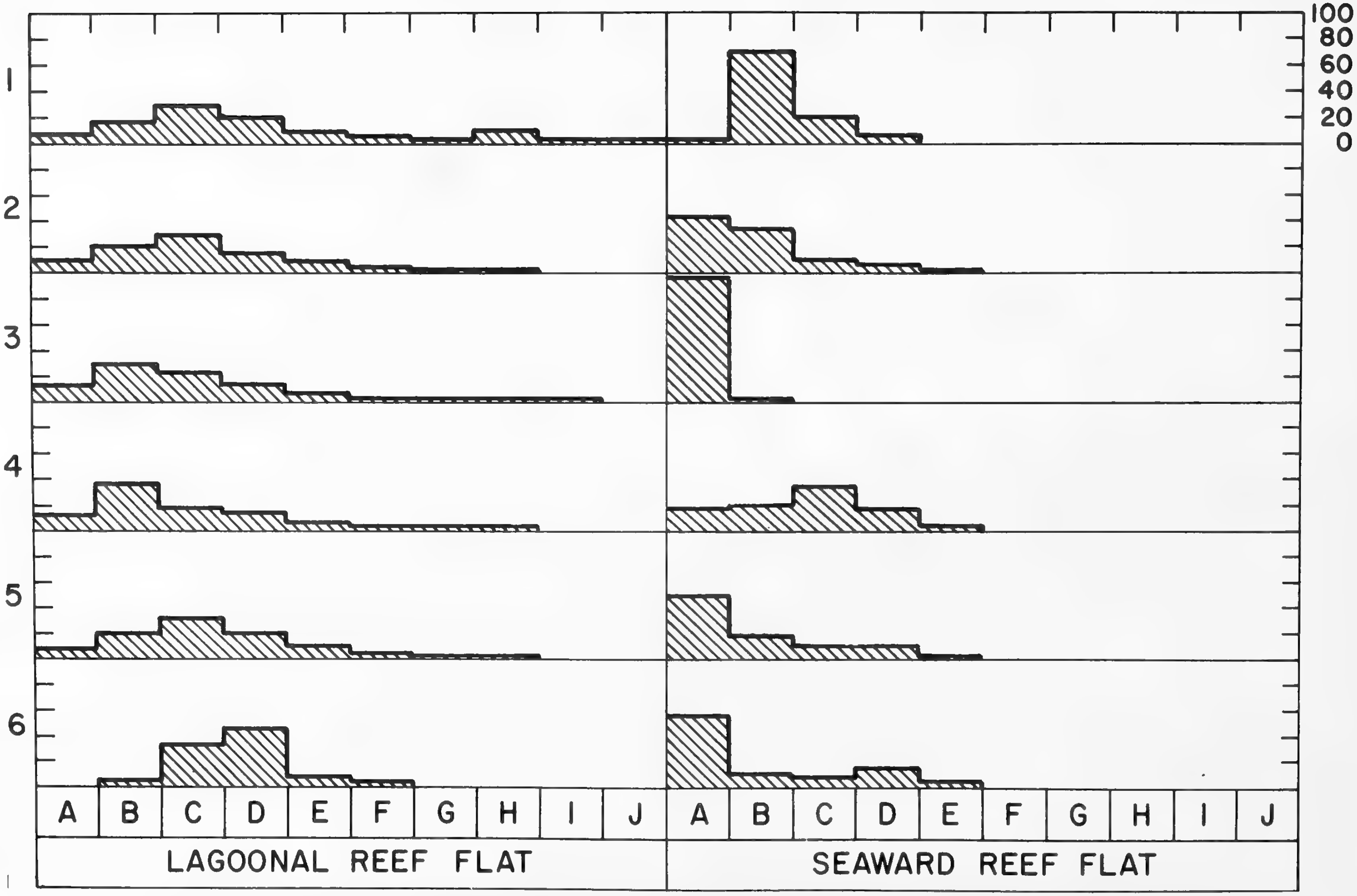

Figure 8: Comparison of aragonite distribution in lagoon and seaward reef flat sediments. Location of samples indicated in Fig. 1. The height of a column in a histogram indicates the percentage of the total sample aragonite that is in the grain size range designated by the corresponding alphabetic character (millimeter equivalents specified in text).

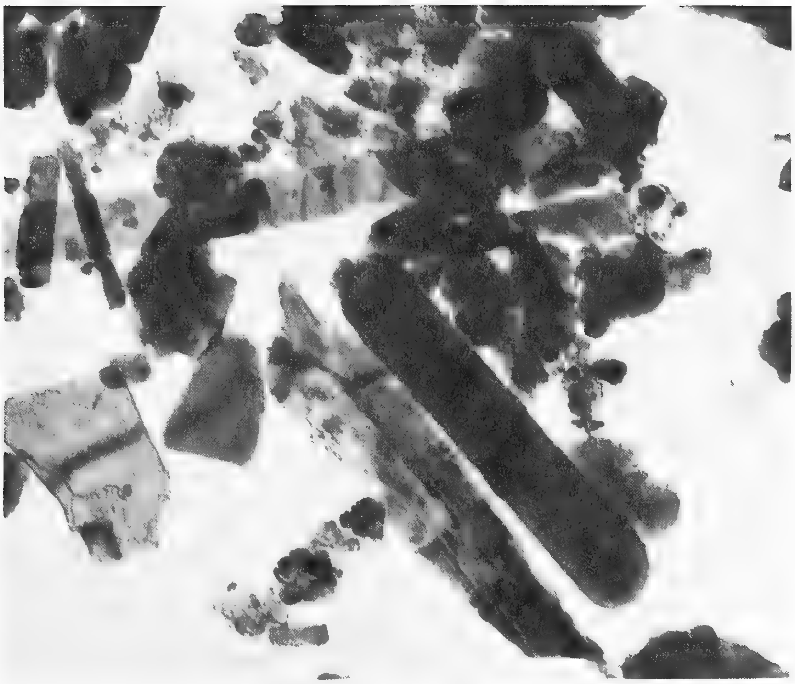

Figure 9: Electron photomicrograph of the fines ($<$0.074mm) from sample TA-8, showing whole and fragmented aragonite needles and laths. The prominent dark colored acicular crystal at lower right is between 1 and 2 microns in length.

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BIRDS SEEN AT SEA AND ON AN ISLAND IN THE CARGADOS CARAJOS SHOALS

by R. Pocklington, P.R. Willis and M. Palmieri

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BIRDS SEEN AT SEA AND ON AN ISLAND IN THE CARGADOS CARAJOS SHOALS

by R. Pocklington, P. R. Willis and M. Palmieri

During a second cruise to the Indian Ocean by the Woods Hole Oceanographic Institution vessel R.V. ATLANTIS II in 1965 as part of the International Indian Ocean Expedition, a return visit was made to the Cargados Carajos Shoals, where we had previously gone ashore in November, 1963 (Pocklington, 1965). No other vessel during the I.I.O.E. had a similar opportunity to observe the western Indian Ocean at opposite seasons with the same personnel and techniques.

The Cargados Carajos are interesting because they are geographically between the Seychelles, where sea-bird species breed mainly in the northern summer (Loustau-Lalanne, 1963), and the Mascarenes, where many sea-birds breed in the southern summer (Newton, 1958). The species list which follows covers records made at sea between Tromelin (15°52'S, 54°25'E), Ile du Sud in the Caragados Carajos Shoals (16°49'S, 59°30'E), Rodriguez, and Mauritius, June 2-7, 1965, inclusive, and ashore on Ile du Sud, June 3. Nomenclature follows Alexander (1955), and names of colors and topography of birds follow Palmer (1962).

Puffinus lherminieri Audubon's Shearwater

One at 18°52'S, 62°13'E, 4 June, in the vicinity of Rodriguez. Bailey (1968) saw few more than 50 miles from their breeding grounds, and Gill (1967a) found them common only in the vicinity of the Seychelles, Mauritius and Reunion, but not in the intervening seas, which hints at islands off Rodriguez as possible breeding stations, as suggested by Gill (1967b).

Pterodroma spp. Gad-fly Petrels

On 4 June at 18°52'S, 62°13'E, nine petrels with grey upper-parts, white underparts and a dark leading edge to the upper wing, were seen. They were unlike any of the Petrels and Shearwaters with which we were already acquainted. A possibility exists that these birds were Barau's Petrels *Pterodroma baraui* (Jouanin, 1963), of the existence of which we were unaware at the time. This bird breeds on Reunion in the southern summer, dispersing late April/early May for parts unknown (Jouanin and Gill, 1967). A recent examination of subfossil petrel bones from Rodriguez (Bourne, 1968) indicates that gad-fly petrels did breed there, although they apparently no longer do so (Gill, 1967b).

Oceanites oceanicus Wilson's Storm-Petrel

Two storm-petrels, dark with white rumps, seen with the above-mentioned gad-fly petrels, were believed to be this species, which we recorded with decreasing frequency as we went south.

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Phaethon rubricauda Red-tailed Tropic-bird

Two were seen between Cargados Carajos and Rodriguez, one at 18°25'S, 62°13'E, the other at 19°09'S, 62°33'E. It has not been recorded in recent times from Rodriguez (Bourne, 1968), nor from Cargados Carajos (Newton, 1958), though Staub and Guého (1968) mention a red tail-feather picked up on Albatros I, Cargados Carajos. It breeds on the cliffs of Gunners Quoin, Mauritius (Newton, 1958) where many were seen 7 June.

Phaethon lepturus White-tailed Tropic-bird

One adult flew about the ship while the party was ashore on Ile du Sud. No others were seen until we approached Mauritius, 7 June, where they breed (Gill *et al.*, 1970).

Sula dactylatra Blue-faced Booby

Three adults were seen close to Ile du Sud, but they were not nesting there, though they do on Ile du Nord (Newton, 1958; Staub and Guého, 1968). Three more were in a mixed flock with Sooty Terns, *Sterna fuscata*, between Rodriguez and Mauritius, where they breed on Serpent I. (Newton, 1958).

Fregata minor Great Frigate-bird

In addition to numbers of unidentifiable frigates among large flocks of terns feeding off Tromelin, where *F. minor* breeds (Staub, 1970) others were seen between there and Cargados Carajos 16°07'S, 56°05'E, feeding in association with flocks of Sooty Terns. Three all-black males were positively identified among them. No more were seen outside this area.

Fregata ariel Lesser Frigate-bird

Males of this species, identified by white patches on each side of the abdomen, were seen at sea as we approached Ile du Sud. They were soaring over groups of feeding Noddies *Anous* spp. and Sooty Terns. No frigates were seen at sea subsequent to our visit to this island.

On Ile du Sud, there were *ca.* 200 nesting pairs in the N.E. and 60 in the S.W. of the island, an increase over the total of *ca.* 200 pairs nesting in November 1963. The red gular sac of some sitting and flying males was inflated, in contrast to our previous visit, when none of the males showed more than a small shrunken throat-pouch. In the case of the Great Frigate-bird on Tower I. in the Galapagos, Nelson (1968) found that the pouch is inflated for only three or four weeks at the beginning of the breeding season. If this holds true for *F. ariel* then this indicates that the beginning of the breeding season was not long past. Staub, who visited during the latter half of April, 1968, found that "nearly all the males had their red gular pouch fully extended," and that eggs were already present (Staub and Guého, 1968).

Only one juvenile was seen flying over the island, which is in accord with the idea that they disperse away from the breeding stations while the adults remain relatively close by (Bailey, 1968). There were no hatched eggs, in contrast to November 1963, when eggs, naked young and downy chicks were simultaneously present, as shown in published photographs (Willis, 1966). Reference to Table I shows that nesting occurs in both northern and southern summer, in contrast to *F. minor* which breeds only in the southern spring. Also, the duration of the *F. ariel* breeding cycle is no more than 8-9 months, as found by Gibson-Hill (Palmer, 1962), for *F. andrewsi* on Christmas I., near Java, and not 15 to 18 months, as found for *F. minor* on Tower Island, Galapagos (Nelson, 1968), where long before the juveniles from one season were fully independent, the next season began.

The female Lesser Frigate-birds were of two types: bluish-gray bill, black eye-ring, breast pure white with a sharp demarkation between the black of the throat and the white of the breast, side of neck and hindneck white; and, pink bill, rose eye-ring, white breast with cinnamon flecking which destroys the sharp demarkation of throat from breast so characteristic of the other type, side of neck as breast, the white of the hindneck obscured by black and cinnamon flecking. Both types were sitting on nests.

These differences may be due to age or stage of physiological cycle of one form only, but the possibility exists that this represents a stable polymorphism or an overlap of breeding ranges of two previously undescribed forms of this species. Staub confirmed this variation (Staub and Guého, 1968) and noted that "the eggs of the two varieties seem somewhat different in shape and size," a point that we had not noticed. He also noted red eye-ringed females as being more numerous than the black-ringed variety.

Sterna dougalli Roseate Tern

About 200 adults were seen ashore on the sand-pit west of Ile du Sud. There were no young birds as there had been in November 1963. Nesting would appear to be restricted to the southern spring (see Table I) in contrast to the other western Indian Ocean breeding stations of this cosmopolitan species, where nesting is in the northern summer (Watson *et al.*, 1963). On islands at comparable latitude off Western Australia, nesting in both April-June and November-December has been recorded (Serventy and Whittell, 1962).

Sterna fuscata Sooty Tern

This species, by far the most frequently encountered bird in the western Indian Ocean (Pocklington, 1967) as also noted by Parker (1970), was seen in hundreds at sea between Tromelin and Cargados Carajos, but was absent as a nesting species from Ile du Sud. A dozen or so were seen flying over the island: they were probably breeding on other islands of the group (Staub and Guého, 1968). Between Cargados Carajos and Rodriguez, and between there and Mauritius, where they breed (Gill *et al.*, 1970) smaller parties of up to 30 were seen, but they were absent from the immediate vicinity of Rodriguez, as also noted by Gill (1967b) in September-October 1964, though they were present in April (Bourne, 1968).

Anous stolidus Common Noddy

None were seen at sea until we approached the Cargados Carajos reef where parties were feeding in mixed flocks with Roseate and White Terns *Gygis alba.* On Ile du Sud, at least 200 individuals were sitting on eggs and brooding downy young; older chicks and fledglings were running about the island. There were many dead and dying immatures; some were heavily infested with ticks, others by seeds adhering to the feathers, making it impossible for them to move. Parker (1970) noted large numbers of dead and dying juvenile *Sterna fuscata* with *Anous stolidus* on Goelette Island, Farquhar, apparently starving and Bailey (1968) made a similar observation on Desnoeufs Island, Amirantes. Other adult birds were gathered in groups of 50-60 at the water's edge, where pairs were observed *in copula.* Thus, all stages of the breeding cycle were in progress. From the data of Table I it appears that breeding is well nigh continuous throughout the year at this latitude. A similar situation apparently existed on Rodriguez according to ancient records (Bourne, 1968) and recently Common Noddies with young of all sizes were observed in mid-July on Sandy I. off Rodriguez (Bourne, 1968), though they were not breeding there in late September/early October (Gill, 1967b). As we crossed the broad fringing reef of Rodriguez, Noddies *Anous* spp. were the only birds seen. They reappeared off Mauritius where, on Serpent Island, they nest primarily in October and November (Vinson, 1950).

Anous tenuirostris Lesser Noddy

As in November 1963, this species was nesting in low bushes *Tournefortia* sp. on Ile du Sud. It apparently nests continuously there (Table I). On Sandy I., off Rodriguez, there were nests, but no eggs in September/October (Gill, 1967b). The nesting dates on other Western Indian Ocean islands are: Seychelles, throughout the year (Loustau-Lalanne, 1963); Chagos, December/February and, main season, May/August (Loustau-Lalanne, 1962); Mauritius, throughout the year with a peak in September/December (Newton, 1958). Off Western Australia in the Abrolhos Is., hatching is over by mid-November, this being the only breeding season (Serventy and Whittel, 1962). This bird was not seen far out at sea.)

Gygis alba White Tern

Only seen at sea as we approached Ile du Sud. There were about 500 pairs on the island, some sitting on their solitary egg on branches, on pieces of coral, on the ground and even in the guano-collectors' huts. Others were brooding downy young or feeding fledglings. It would appear that nesting in this species is continuous throughout the year at this location (Table I) as it is in the Seychelles (Loustau-Lalanne, 1963) and Rodriguez (Bourne, 1968, Gill, 1967b).

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SUMMARY

A return visit was made in June 1965 to the Cargados Carajos Shoals previously visited in November 1963. These islands are interesting as they lie between the Seychelles, where much breeding is in the northern summer, and the Mascarenes, where many species breed in the southern summer. Records are also given of all species seen at sea between Tromelin, Cargados Carajos, Rodriguez and Mauritius.

Lesser Frigate-birds, *Fregata ariel,* were nesting on the island in Cargados Carajos. Our visit coincided with the beginning of the breeding season. Other nesting birds were Common Noddy *Anous stolidus,* Lesser Noddy *Anous tenuirostris,* White Tern *Gygis alba* for which a continuous breeding cycle at this latitude is inferred.

Birds seen at sea include petrels, storm petrels, tropic-birds, boobies, and terns, all in small numbers at this season.

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Table I. RECORDS OF BIRDS BREEDING ON CARGADOS CARAJOS SHOALS

Puffinus pacificus	young					nests
Sula dactylatra	breeding pairs		adults only		breeding pairs	breeding pairs
Sula sula	nests	adults only				
Fregata minor	nests	not nesting		adults only	breeding pairs	nests
Fregata ariel	young	nests & some eggs	eggs only		eggs & young	young
Sterna dougalli	young		not breeding		young only	eggs & young
Sterna fuscata	young		not breeding	eggs young	adults only	a few young
Anous stolidus	eggs & young?	eggs & some young	eggs & young	young	eggs	eggs
Anous tenuirostris	nests		eggs & young	eggs	nests	nests
Gygis alba	eggs & young ?		eggs & young	eggs	eggs	eggs
Months	Jan.	Apr.	June	Aug.	Nov.	Dec.
Visitors	Newton	Staub	Pocklington *et al.*	Gardiner & Cooper	Staub, Pocklington *et al.*	Staub & Guého
Years	1955 1956	1968	1965	1905	1963 1964 1965	1965

APPENDIX

While this paper was in preparation, important accounts of seabirds breeding on other oceanic islands in the tropics were published. These are by Bourne (1971) on the birds of the Chagos Group (5°20' - 7°35'S, 71°20' - 72°40'E), Schreiber and Ashmole (1970) on Christmas Island in the Pacific Ocean (2°N, 157°W) and Harris (1969) on the Galapagos Islands (1°50'N - 1°20'S, 89°-92°W). We wish to review the records of birds breeding on Cargados Carajos Shoals in the light of this new information. To avoid repetition, the names of the Islands will serve to identify the authors; also Tromelin to indicate Staub (1970).

Puffinus pacificus Wedge-tailed Shearwater

Occurs in the offshore waters of the Chagos Group during most of the year and reported to breed on some outer islands from November to February. It therefore appears to breed in the same season (southern summer) in the Cagador Carajos (Table 1) as in the Amirantes (Parker, 1970), Chagos and Round Island off Mauritius (Gill *et al.*,1970). In contrast, on Christmas Island in the equatorial Pacific, few are even present from November to January. The peak period for eggs is June to July and for chicks August to October, i.e. northern summer and fall.

Sula dactylatra Blue-face Booby

On Christmas Island it lays at all times of the year but mainly from April to October. In the Galapagos it has an annual cycle, with colonies out of phase by up to four months. In the Western Indian Ocean the November to January breeding on Cargados Carajos compares with the October to November peak on Serpent Island (Vinson in Gill *et al.*, 1970), the October peak on Latham Island off the East African Coast, 97 km south of Zanzibar (Parker, 1970), and the peak period of reproduction from November to March on Tromelin, to indicate a similar out-of-phase annual cycle.

Sula sula Red-footed Booby

This bird has been reported to breed in the Chagos Group in both July and September. On Christmas Island, some egg-laying occurs in all months. There are two peak periods from April to May and December to January. In the Galapagos (Tower Island only) it is suggested that the breeding cycle is less than one year to account for the different peak laying months in different years, though eggs have been found in every month. On Tromelin nesting has been noted in August, November and February in different years so the situation there might be comparable. The bird has now disappeared as a breeding species from Cargados Carajos (Staub and Guého, 1968).

Fregata minor Great Frigate-bird

On Christmas Island most laying is late March to May, with chicks but no eggs September to January. The birds are on individual cycles because of the greater-than-annual cycle of successful breeders. There is more precise synchrony within than between colonies. In the Galapagos there are annual breeding cycles on individual islands but breeding is not in phase on different islands. The available evidence from Cargados Carajos indicates laying from November to January as compared with a late August start on Tromelin, so a situation similar to that in the Galapagos may apply.

Fregata ariel Lesser Frigatebird

On Christmas Island this bird lays from late April to May. By January no eggs, chicks or adults remain. One definite breeding season during the northern spring and summer is

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implied. In the Cargados Carajos nesting was also observed starting in late April (Staub and Guého, 1968) at the beginning of the cool dry season. Eggs and young are also present from November to January at the start of the warm wet season. On Tromelin, 480 km due west, the species was not breeding in late August, so one long breeding period seems less likely than two discontinuous ones at this latitude.

Anous stolidus Common Noddy

In the Chagos there are apparently two main breeding seasons, May to August and December to February but nesting from September through November has also been reported. On Christmas Island eggs have been found throughout the year but fewer from July to November than in other months. In the Galapagos, breeding is continuous but there are only a few eggs from August to October.

Anous tenuirostris Lesser Noddy

This bird nests in trees in the Chagos in June and November through December. On Christmas Island there is one definite breeding season in the northern spring, laying mainly from April to May. On Serpent Island both *A. stolidus* and *A. tenuirostris* nest primarily in October and November (Vinson in Gill *et al.*, 1970). On the basis of these comparative data there may be discontinuities in the breeding of these species on Cargados Carajos during those months, in particular February to May, which corresponds to the northern fall non-breeding season at Christmas Island. This statement supercedes our previous inference about the two noddies (see pp. 3, 4).

Gygis alba White or Fairy Tern

In the Chagos Group it has been found nesting in trees in all islands in February, May to July, September and October, and December. On Christmas Island substantial numbers of eggs are laid in all months, the minimum being around November. By analogy, continuous breeding at Cargados Carajos is therefore likely.

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GEOMORPHOLOGY AND VEGETATION OF ILES GLORIEUSES

by R. Battistini and G. Cremers

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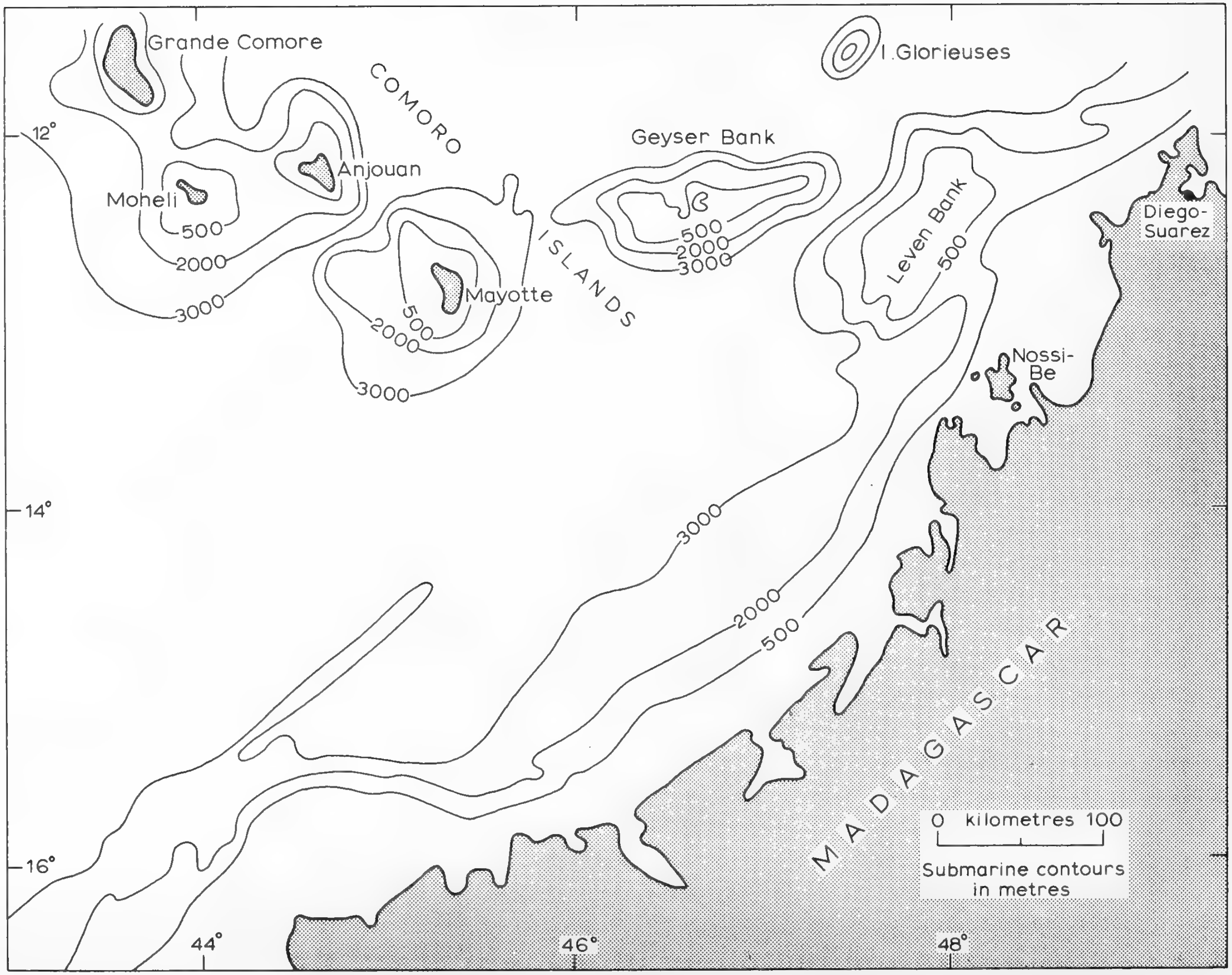

Figure 1. Location of Iles Glorieuses

GEOMORPHOLOGY AND VEGETATION OF ILES GLORIEUSES

by R. Battistini[1] and G. Cremers[2]

INTRODUCTION

The present study was carried out with the assistance of the O.R.S.T.O.M. oceanographic vessel *Vauban*, a 24.5 m trawler. The field party, which spent the three days 28, 29 and 30 January 1971, on the islands, consisted of R. Battistini, geomorphologist, of the Université de Madagascar, G. Cremers, botanist, of O.R.S.T.O.M., and A. Crosnier, director of the Centre O.R.S.T.O.M. at Nossi-Bé.

The Iles Glorieuses are situated north of the Mozambique Channel, at 11°30'S latitude and 47°20'E longitude. The group consists of two islands, Grande Glorieuse and Ile du Lys, located on a large coral platform 17 m long and aligned southwest-northeast. The outer slopes of the platform are extremely steep (between 20° and 35° on the south and southeast sides between 75 and 1500 m depth), suggesting that the coral has a volcanic basement. No volcanic rocks outcrop, however, and the depth of the basement beneath the coral is not known.

There is a meteorological station on Grande Glorieuse, maintained by the Service Météorologique de La Réunion, which has operated for about ten years. The mean annual rainfall is 1012 mm, and the mean monthly figures are as follows:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
206.3	152.9	151.7	95.7	83.7	67.9	38.5	59.7	11.4	5.1	20.1	119.0

The prevailing winds are the Southeast Trades, with 42.3% of the observations in the sectors ENE, E and ESE, except for January and February when the dominant winds are W, WNW and NW (37.9% in January, 38.8% in February).

ACKNOWLEDGEMENTS

We thank the Centre Océanographique of O.R.S.T.O.M. at Nossi-Bé, and especially its Director, M. Alain Crosnier, for the welcome andassistance given to us during this expedition. We thank also Commandant Fiuric of the *Vauban* and his crew. M. Poonoosawny, in charge of the meteorological station, and his three colleagues also assisted in this work, and we are glad to thank them here. We thank the Service Météorologique de La Réunion, and particularly M. Malick, for the climatic statistics. Cremers also thanks Dr. J.-L. Guillaumet and A. Rakotozafy for their valuable aid.

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GEOMORPHOLOGY OF THE ILES GLORIEUSES

by R. Battistini

Grande Glorieuse

Grande Glorieuse, at the southwest end of the reef, is oval-shaped, with a maximum length of 2300 m and width of 1700 m. It is a low sandy island, formed during the Flandrian by the accretion of a large number of parallel beach-ridges. The beach-ridge morphology is obscured in the east and northeat by dune-formation: on this side of the island there is a large dune field, reaching a height of 12 m, covered and fixed by a dense vegetation of *Casuarina* and other species. The northeast and east coasts are the only ones to have a narrow zone of active dunes, with nebkas and small parabolic dunes, formed by the dominant easterly winds.

On the south and southeast coasts the beach crest is a sandy storm ridge, completely covered with a shrubby vegetation of *Scaevola* and *Cordia,* and without dunes. Water from storm waves covers the vegetation and reaches up to 10 m inland from the beach crest. The west coast, formed by lower flatter beach ridges, also lacks dunes. The centre and western part of the island is occupied by a large but now abandoned coconut plantation.

In the south and southwest the Flandrian sand deposits abut against the karst-eroded remains of an older reef structure which we correlate with the Karimbolian high stand of the sea (probably about 125,000 yr B.P.); these remnants are named Ile aux Crabes, Rocher Champignon, and Rochers du Cap Vert. They consist of banks of limestone with *Tridacna* and with large coral heads in the position of growth, covered at Ile aux Crabes with shelly limestones with rolled coral debris, reaching up to about 3 m above the level of present highest tides. The limestones are deeply dissected into large lapiés, with tidal notches and overhanging visors overlooking a low-tide platform, smooth or with enclosed pools, in the same old limestones.

These limestone remnants include in their upper parts inclusions, brown to black in colour, some of several cubic metres in size, which appear to have formed in old solution holes and are now consolidated. The upper surfaces of the inclusions are eroded like the rest of the limestones. Bone fragments and pieces of carapace of an unidentified tortoise have been obtained with difficulty from these inclusions. Similar inclusions, but without bones, have been described at Europa (Battistini, 1965, 1966; Berthois and Battistini, 1969).

The coast zonation in the west and south is as follows:

(1) the beach, which is always sandy.
(2) beachrock, of which there are only three outcrops, two on each side of Ile aux Crabes, and one to the southeast of Cap Vert.
(3) a platform of reef limestone, 300-500 m wide, which dries almost completely at low water; as at Europa, this is probably largely an eroded pre-Flandrian structure.
(4) a rubble zone of small boulders.

Beyond the rubble zone, the grooved outer slope had little living coral at the two places where it was observed. In shallower water it is covered with banks of *Halimeda* sand, with, in deeper water, isolated coral heads, which are more numerous between 15 and 35 m depth.

Ile du Lys

Ile du Lys, about 600 m long, is much smaller than Grande Glorieuse. It is almost entirely formed of reef limestones with *Tridacna* and coral heads in the position of growth and by stratified beds of reef debris of pre-Flandrian age. On the north side, exposed to the heavy swell, the limestones are eroded along their whole length into lapiés, in places with overhangs 4-6 m high. The northwest point is a karst-eroded plateau 3-5 m above the level of present highest tides, scattered with large coral heads in the position of growth. The old coral limestone is here covered by stratified deposits, dominated by *Halimeda* debris; some of these deposits seem old, but others are recent, and are probably storm deposits cemented to form beachrock, since they contain copper nails from a wreck.

The coast zonation on the north side is as follows:
(1) storm beach overlying the coral limestone.
(2) high-tide platform with lapiés and pools with undercut edges.
(3) cliff with large pinnacles, with or without visor, 4-6 m high, cut in old coral limestone.
(4) low-tide platform, with large smooth grooves perpendicular to the shore, cut in the same old limestone.
(5) shallow channel with some patches of *Halimeda* sand and marine grasses.
(6) rocky outer rim, 0.5-1 m in height, consisting of old coral limestone with superficial incrustation by recent calcareous algae.
(7) outer slope, with some large living coral heads.

Bedded detrital limestones, with dips of up to 15°, formed of coral and shell debris, outcrop on the east and west sides of the island. These deposits overlie the massive coral limestones of the north, but, with the exception of some outcrops near the leeward point which are probably Flandrian beachrocks, they are placed in the same period (Karimbolian).

In the centre of the island there is a shallow pool, with outflow to the north, with a vegetation of *Pemphis acidula*. The pool is tidal, and is reached by storm waves across the shrub-covered storm ridge on its northern side.

The whole of the leeward or southern part of the island consists of guano mixed with beds of *Halimeda* sand, of a yellow to light brown colour, with a vegetation of *Tournefortia*. This area includes the highest point on the island (11 m). A sand spit is forming towards the south on this leeward side, and is colonised by a few patches of grass.

The island is inhabited by thousands of rats, which probably arrived either on the wrecked ship the remains of which are visible near the pool outflow in the north, or during a recent attempt at settlement from which a cistern and some other articles remain. There is now only a small colony of terns, preserved from the rats on mushroom rocks of *Halimeda* limestone at the western end of the island.

The Reef flat and Roches Vertes

The upper surface of the reef was traversed with an outboard to the south of Ile du Lys and between Grande Glorieuse and Roches Vertes. It is almost entirely sandy, with higher sandy banks drying at low water.

The Roches Vertes form a group of four rocks entirely constituted of the same reef limestone, with large coral heads in the position of growth, that outcrops at Ile du Lys and in the south of Grande Glorieuse, of Karimbolian age. Their upper surface, with small-scale karst erosion, carries a skeletal soil with a low halophytic vegetation of *Sesuvium portulacastrum*, at least on the two southwest Roches. A very large colony of terns survives here.

The coral limestone has inclusions of brown and black material, with bone fragments, identical to that described on Grande Glorieuse and also found in the northeast of Ile du Lys, which we interpret as the lithified fill of ancient solution holes. The Roches are dissected into large lapiés and mushroom rocks, standing on a low-tide platform of the same old coral limestone.

CONTRIBUTION TO BOTANICAL KNOWLEDGE OF ILES GLORIEUSES

by G. Cremers

Formation and evolution of the islands

The Iles Glorieuses are formed of coral and algal sand, with outcrops of coral limestone on the west coast of Ile du Lys, at Cap Vert on the southwest coast of Glorieuses, at the small Ile aux Crabes to the south of the main island, and forming the Roches Vertes. The process of development of the islands is most apparent on Glorieuse, which covers 4 sq km.

In the field we observed zones of parallel dunes, especially in the southern part of the island. Air photographs taken by the French Army based at Diego Suarez have confirmed that this is an area of progradation. Conversely in the north-north-west is a zone of erosion. The general tendency is towards an increase in the surface area of the island.

This evolution has resulted in a zonation of vegetation as well as of relief. From the periphery towards the centre the main zones are:
(1) the beach,
(2) the zone of dunes, well-marked on the south and east coasts but eroded away in the north,
(3) a shallow depression on the landward side of the dunes, swept by waves overtopping the dunes during periods of high tides and cyclones,
(4) the central zone, covering the main part of the island. This has a dense vegetation of shrubs and small trees, with a few taller trees. It is probable that the whole central area was once covered by this vegetation, which is now confined to the east and south. The west of the island is occupied by a coconut plantation, now abandoned and more or less invaded by other species. Between the plantation and the natural woodland there is a zone of degraded vegetation. Finally the existence of the airstrip has favored the establishment of numerous herbs not found elsewhere.

Botanical history of the islands

The first botanical report on the Iles Glorieuses which has been found is that of Coppinger (1882). He found "a dense vegetation of primary forest" on Grande Glorieuse, and on Ile du Lys a wooded region with *Ficus, Hibiscus* and *Scaevola,* and with *Pemphis* in the mangrove.

The islands have been officially administered by France since 23 August 1892, although a French colonist, M. Caltaux, had already lived there for ten years.

Abbott (1893) found 30 species of plants on Grande Glorieuse, and trees 15-20 m high in the mangroves on du Lys. The vegetation has clearly been much altered and impoverished since this time. Nicoll (1908) also visited the islands. According to the report of Captain Lebègue on 16 November 1921, the plantation on Grande Glorieuse consisted of 6000 coconut palms, with a population of 17 Seychellois. The settlement was in the northwest part of the island. The vegetation, apart from the plantation, some maize, and *Casuarina,* was a stunted scrub. The Ile du Lys was uninhabited, but there were numerous traces of attempts at exploiting the guano. A herd of about 200 goats was on this island.

While it was thought that the islands were uninhabited, the visit of the lightship *Marius Moutet* in February 1954 revealed that a colonist from the Seychelles had lived there for about a dozen years and the plantation had increased to about 15,000 trees.

At the time of our visit in 1971, there were four men from Réunion, members of the Service Météorologique de la Réunion living on Grande Glorieuse. The herd of goats had disappeared from Ile du Lys, but had been replaced by a larger number of rats.

Vegetation

Grande Glorieuse:

On this island of 4 sq km, 43 species of plants have been found, some of them brought by man. These include *Cocos nucifera*, but also *Carica papaya, Flacourtia ramontchii* (the fruits of which are eaten), *Ricinus communis*, and perhaps *Catharanthus* sp.

(1) Dune belt (Plate 13):

As already pointed out, there is a well developed zone of dunes in the south of the island, but they have been eroded away in the north. The vegetation consists of a woodland 4-5 m high at the top of the dunes, the width varying with the terrain. This woodland consists essentially of three species of small trees. One with orange flowers, particularly abundant, is *Cordia subcordata*. The others are *Scaevola taccada* and *Guettarda speciosa*. On these trees is a lichen of the genus *Rocella* and the parasitic vine *Cassytha filiformis*. The trees are all heliophiles, with leaves at the ends of branches, forming a canopy with an understorey of *Achyranthes aspera*. *Suriana maritima* is another shrub scattered through the trees. In the open areas there are several creeping herbs, such as *Launea sarmentosa, Sida ovata, Boerhavia repens*, and a sterile grass which has not been determined but which may be *Tricholaena monachme* (no. 1356).

(2) Depression inland from the dunes (plate 13):

In this depression, submerged during high tides, one finds almost exclusively the sedge *Fimbristylis abbreviata*. The young plant forms a tuft, which increases in diameter as the plant grows; the inner parts die so that the living parts of mature plants form rings (Plates 14 and 15). One finds also certain species from the dune belt, such as *Achyranthes aspera*, which is much more stunted than in the shade, an unidentified grass (no. 1356), another (no. 1394) which may be *Dactyloctenium aegyptium*, and also *Portulaca oleracea* which is not found in the interior of the island.

(3) Centre of the island:

It is the area south of the airstrip which we have attempted to study in greatest detail, in spite of the difficulties of penetrating the vegetation of small trees and shrubs. The area to the north has been much influenced by man, with the coconut plantation, the old and the new meteorological stations, the trial airstrip, and the present airstrip at an angle to the first.

(a) Natural vegetation (Plate 16):

This consists of a dense woodland 2-4 m high. The most numerous tree is *Tournefortia argentea*, forming small dome-shaped strongly-branched trees which were found in all stages of flowering and fruiting. The other species is *Scaevola taccada*, each plant covering a smaller area than one of *Tournefortia*. This species was fruiting, although it was in flower on the dunes. Parasitic *Cassytha filiformis* is very common on these trees. Several large isolated trees dominate the area: *Cordia subcordata* and *Guettarda speciosa* (fruiting). The herbaceous stratum is almost non-existent, except in open areas, where we find the sterile grass (no. 1356) and *Fimbristylis abbreviata*.

(b) Degraded vegetation:

Along the airstrip, apart from two trees, *Flueggea microcarpa* and *Colubrina asiatica*, one finds mainly prostrate herbs of which the seeds have probably been brought by aircraft. They include *Sida rhombifolia*, two species of *Phyllanthus* (nos. 1368 and 1369), one species of *Cyperus* (no. 1383), and *Portulaca oleracea*.

In the coconut plantation, *Casuarina equisetifolia*, which was planted along the shore as a windbreak, has multiplied greatly since the plantation was abandoned and is now found throughout. The same is true of the very abundant *Ficus* sp. (no. 1410). Several other species are widely distributed, such as *Fluegga microcarpa*, *Colubrina asiatica*, and tufts of *Cyperus* sp. (no. 1383). At the edge of the plantation is a big *Terminalia catappa*, with *Stachytarpheta jamaicensis* and *Ipomoea* sp. (no. 1390) beneath. Several *Flacourtia ramontchii* have been planted along the paths.

In the north of the island, other species are growing at the site of the former meteorological station and at the cemetery. Human influence is clear in the importation of *Carica papaya*, *Ricinus communis*, *Gossypium brevilanatum*, and probably also of *Acalypha* sp. (no. 1374), *Adenia* sp. (no. 1385), *Caesalpinia bonduc*, *Catharanthus* sp. (no. 1375), and *Ipomoea* sp. (no. 1379).

(c) Pool:

There is a small tidal pool in the northwest part of the island, which dries completely at low water. Round its margins grow the shrub *Suriana maritima*, herbs, *Sporobolus virginicus*, and an undetermined sterile grass which may be *Tricholaena monachme* (no. 1378).

(d) Beach:

Several different species are found on the shore in the north of the island. These are *Sporobolus* aff. *virginicus*, *Ipomoea pes-caprae*, *Tribulus cistoides*, and *Wedelia biflora*.

Ile du Lys:

This much smaller island, a few hundred meters long, is poor in species, with a total of only 8. Overtopping by waves during very high tides may be the reason for this poverty.

One can see no zonation in the little vegetation which now exists on the island. Trees of *Tournefortia argentea*, characterized by their dome-shaped appearance, are found almost everywhere round the periphery of the island. In the higher southern part, however, they are much bigger, reaching a height of 5 m and crown diameters of 10-12 m (plate 17). The small trees growing amongst them are *Thespesia populnea*, also in full flower. Behind these trees one finds several trees of *Ficus* sp. (no. 1403), completely leafless at this time, though on some buds have started to develop. This *Ficus* is close to no. 1410 of Grande Glorieuse and is not the *Ficus marmorata* found at Europa I. (Bosser, 1952).

In the east there are large clumps of *Sclerodactylon macrostachyum*. In the west a sterile sedge (no. 1406), which could not be determined, grows in crevices in the coral rock. In the northwest there is a pool open to the sea: around it and within it there are very numerous shrubs or small trees of *Pemphis acidula* (photo 19).

The centre of the island is formed by a large flat plain. There are two clumps of coconuts, comprising five plants in total. All around, plants of a *Boerhavia* species (no. 1408), although completely desiccated, form the first stages of vegetation (plate 18).

Roches Vertes

The Roches Vertes are always emerged, though constantly swept by waves and spray. A patch of *Sesuvium portulacastrum* has been found.

Flora

The plant specimens collected during the expedition are deposited in the Herbarium, Laboratoire de Botanique, Centre O.R.S.T.O.M., Tananarive, Madagascar, and some have been sent to the Herbarium, Muséum National d'Histoire Naturelle, Paris.

Grande Glorieuse

Acalypha sp.	Euphorbiaceae
Achyranthes aspera L.	Amaranthaceae
Adenia sp.	Passifloraceae
Boerhavia sp.	Nyctaginaceae
Boerhavia repens L.	Nyctaginaceae
Caesalpinia bonduc (L.) Roxb.	Caesalpiniaceae
Carica papaya L.	Caricaceae
Casuarina equisetifolia L.	Casuarinaceae
Cassytha filiformis L.	Lauraceae
Catharanthus sp.	Apocynaceae
Cocos nucifera L.	Palmae
Colubrina asiatica (L.) Brongn.	Rhamnaceae
Cordia subcordata Lam.	Boraginaceae
Cyperus sp.	Cyperaceae
Dactyloctenium aegyptium (L.) Willd. (?)	Gramineae
Ficus sp.	Moraceae
Fimbristylis abbreviata Boeck.	Cyperaceae
Flacourtia ramontchii L'Hérit.	Flacourtiaceae
Flueggea microcarpa Bl.	Euphorbiaceae
Gossypium brevilanatum Hochr.	Malvaceae
Guettarda speciosa L.	Rubiaceae
Ipomoea pes-caprae (L.) R. Br.	Convolvulaceae
Ipomoea sp.	Convolvulaceae
Launaea sarmentosa (Willd.) Kuntze	Compositae
Phyllanthus sp.	Euphorbiaceae
Phyllanthus sp.	Euphorbiaceae
Portulaca oleracea L.	Portulacaceae
Ricinus communis L.	Euphorbiaceae
Rocella sp.	Lichenes
Scaevola taccada (Gaertn.) Roxb.	Goodeniaceae
Sida ovata Forsk.	Malvaceae
Sida rhombifolia L.	Malvaceae
Sporobolus virginicus Kunth	Gramineae
Sporobolus aff. *virginicus* Kunth	Gramineae
Stachytarpheta jamaicensis (L.) Vahl	Verbenaceae
Suriana maritima L.	Simaroubaceae
Terminalia catappa L.	Combretaceae
Thespesia populnea (L.) Sol. ex Correa	Malvaceae
Tournefortia argentea L. f.	Boraginaceae
Tribulus cistoides L.	Zygophyllaceae
Tricholaena monachme Stapf. & Hubb. (?)	Gramineae
Wedelia biflora (L.) DC.	Compositae

Ile du Lys

Boerhavia sp.	Nyctaginaceae
Cocos nucifera L.	Palmae
Cyperaceae indet.	
Ficus sp.	Moraceae
Pemphis acidula Forst.	Lythraceae
Sclerodactylon macrostachyum (Berth.) A. Cam.	Gramineae
Thespesia populnea (L.) Sol. ex Correa	Malvaceae
Tournefortia argentea L. f.	Boraginaceae

Roches Vertes

Sesuvium portulacastrum (L.) L.	Aizoaceae

From this list it is apparent that the species found on Ile du Lys and Roches Vertes are not found on Grande Glorieuse, in spite of the small distance between them, and this can be explained by the edaphic differences between the islands. The species found only on Ile du Lys are *Pemphis acidula, Sclerodactylon macrostachyum, Ficus* sp., a species of sedge, and *Boerhavia* sp. *Sesuvium portulacastrum* is only found on Roches Vertes.

Two species are not found in Madagascar. Some are pan-tropical and are found everywhere, others are cultivated; in fact these last have a very well-marked distribution and are most numerous on the west coast. However *Launea sarmentosa, Scaevola taccada, Tournefortia argentea* are only found on the east coast. *Sporobolus* aff. *virginicus* is very similar to the form on the east coast. One species is a Malagasy endemic, *Gossypium brevilanatum,* and has clearly been brought by man.

The two species not known in Madagascar are *Wedelia biflora* and *Sida ovata.* The first is found on the shores of the Indian Ocean, in the Comoros and at Juan de Nova I. The second has been collected at Tromelin I. by Paulian in 1953 (unnumbered specimen). According to Hutchinson and Dalziel (1954) this species is distributed in Africa with extensions to Arabia and India.

Three species *(Colubrina asiatica, Fimbristylis abbreviata, Launaea sarmentosa)* are not recorded from Europa or Juan de Nova. No comparison has been made with the islands to the north of Iles Glorieuses.

Certain species recorded by Hemsley (1919) have not been found during the present investigation. These are:

Apodytes mauritiana Planch. (Icacinaceae) = *A. dimidiata* E. Mey. Distribution: East Africa, Mascarenes, Comoros, Madagascar, Cosmoledo, Astove, Aldabra.
Boerhavia diffusa (Nyctaginaceae). Pantropical.
Cleome strigosa Oliv. (Capparidaceae). East Africa, Madagascar, Aldabra, Astove.
Cucumis trigonus Roxb. (Cucurbitaceae). East Indies.
Cyperus rotundus (Cyperaceae). Pantropical and subtropical.
Eragrostis tenella (Gramineae). The name of the author was not given by Hemsley, and it is hence not possible to define this species, which may be related to:
- *E. tenella* Benth. = *E. interrupta* Beauv. Africa, Asia, tropical Australia;
- *E. tenella* Nees = *E. pilosa* Beauv. Tropical regions;
- *E. tenella* Roem. et Schult. = *E. plumosa* Link. Tropical Asia and Africa; but is more likely:
- *E. tenella* (L.) Beauv = *E. amabilis* (L.) W. & A.

Euphorbia prostrata Ait. (Euphorbiaceae). Pantropical.
Ficus aldabrensis Baker (Moraceae). Aldabra, Assumption, Cosmoledo, Astove. = *F. reflexa* Thunb.
Ficus nautarum Baker (Moraceae). Seychelles, Aldabra, Assumption, Cosmoledo, Astove, St Pierre.
Hibiscus hornei Baker (Malvaceae) = *H. physaloides* Guill. et Perr. Tropical and subtropical Africa, Comoros, Madagascar; probably introduced.
Ipomoea glaberrima Boj. ex Hook. (Convolvulaceae) = *I. macrantha* R.& S. Tropical coasts and islands.
Plumbago aphylla Boj. (Plumbaginaceae). Aldabra, Assumption, Cosmoledo, Astove, Madagascar.
Portulaca quadrifida L. (Portulacaceae). Tropical coasts and islands.
Sida spinosa L. (Malvaceae). Pantropical.
Solanum nodiflorum Jacq. (Solanaceae) = *S. nigrum* L. Pantropical.

Some of our undetermined species may correspond with some of those in this list.

Conclusion

It is clear from the reports of early visitors that the vegetation of the islands has been transformed. It appears that the vegetation was formerly quite dense: primary forest in 1882; trees 15-20 m tall in the mangrove of Ile du Lys in 1893. In 1921 a coconut plantation replaced part of the forest and only shrubby vegetation remained on Grande Glorieuse. On Ile du Lys there is no longer any trace of big trees in the mangrove.

If the number of species present has increased, from 30 in 1893 to 48 in 1971, the influence of man is the main reason. Some herbaceous species have been introduced by aircraft following the construction of the airstrip.

As Capuron (1966) has suggested for Europa I., since these islands have no economic value, it would seem useful to protect their fauna and flora in order to be able to study their natural development.

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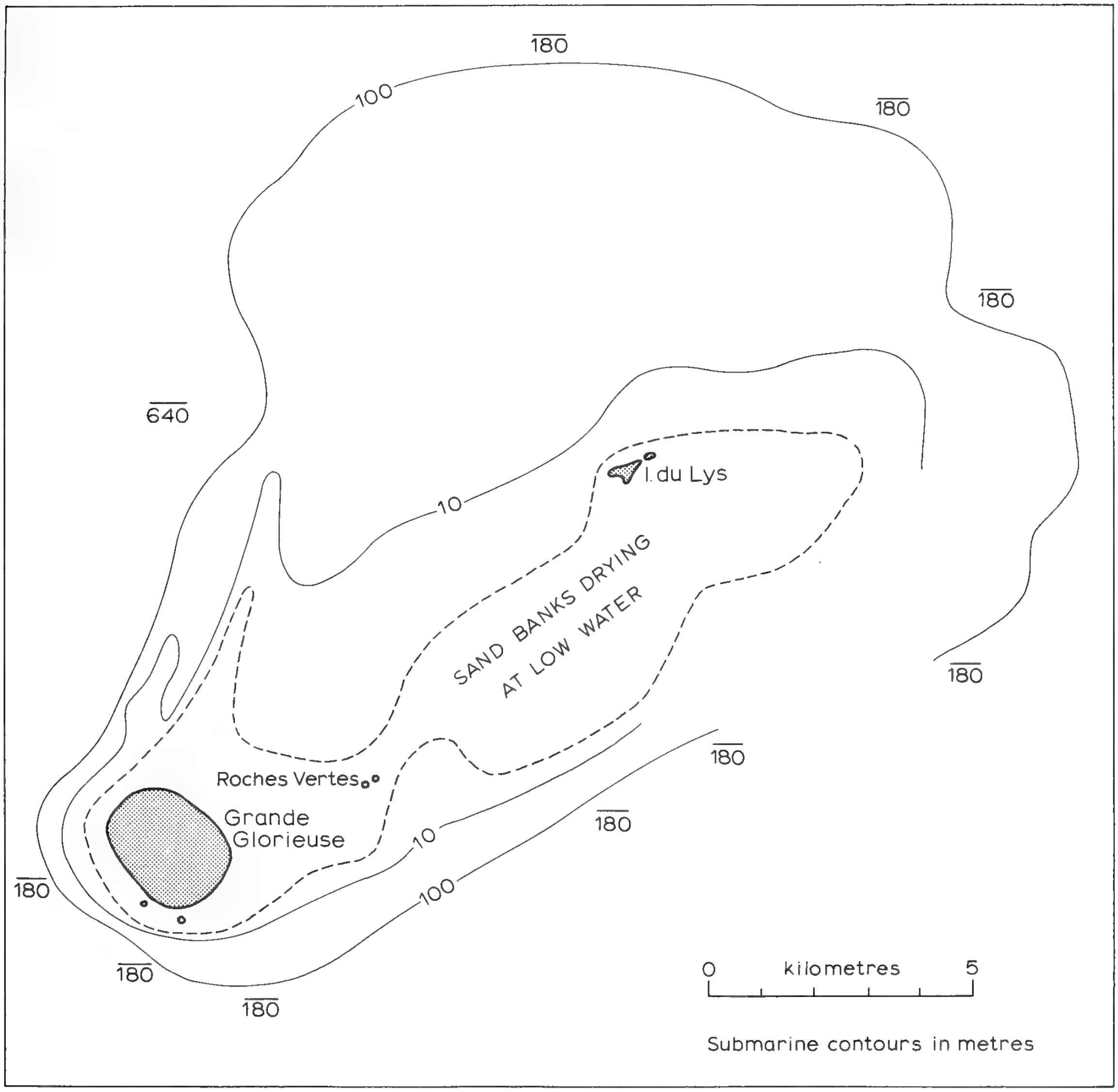


Figure 2. Iles Glorieuses, in part after hydrographic chart

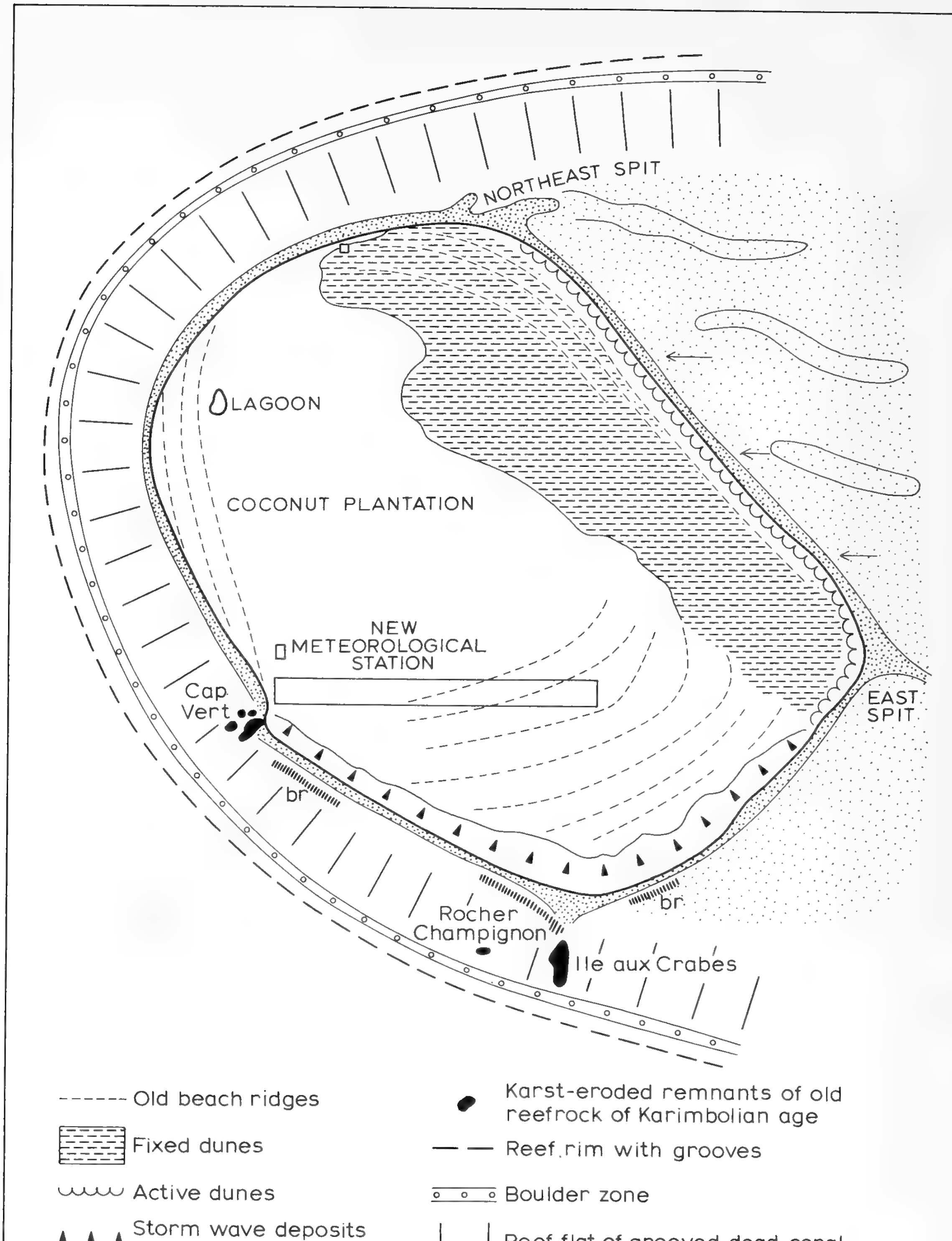
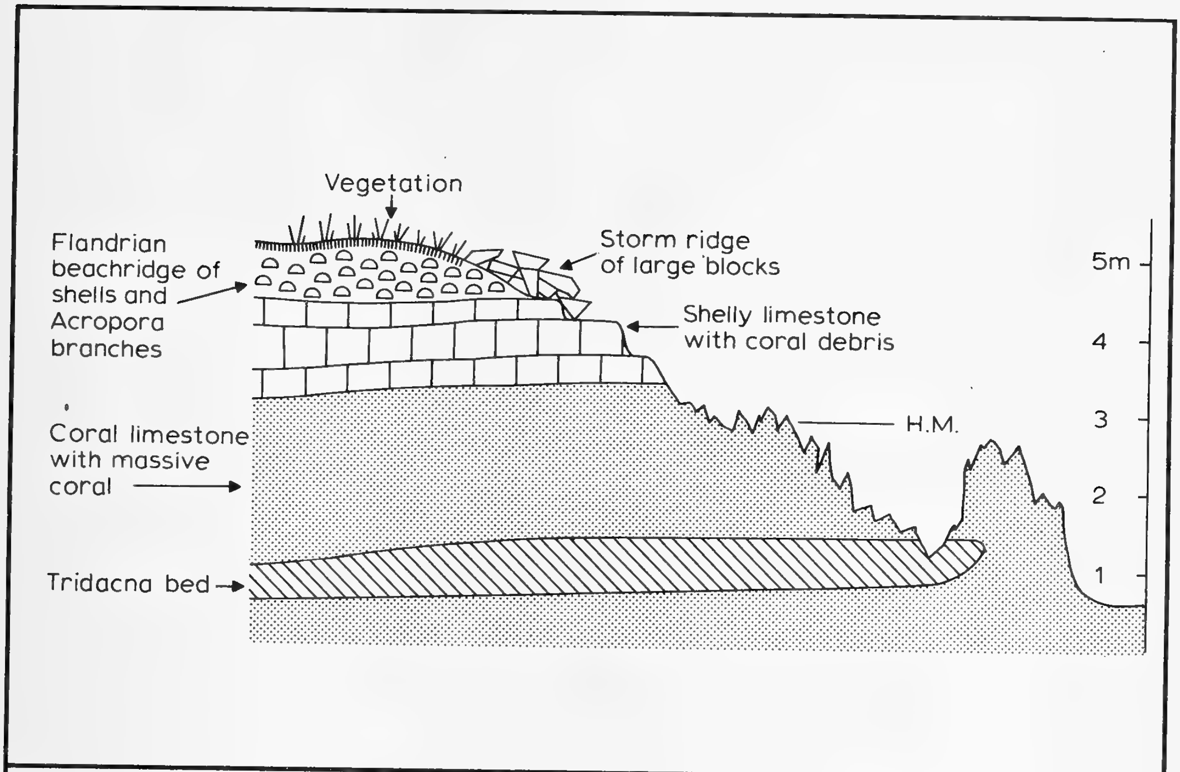


Figure 3. Geomorphic sketch-map of Grande Glorieuse

Figure 4. Section in the southern part of Ile aux Crabes



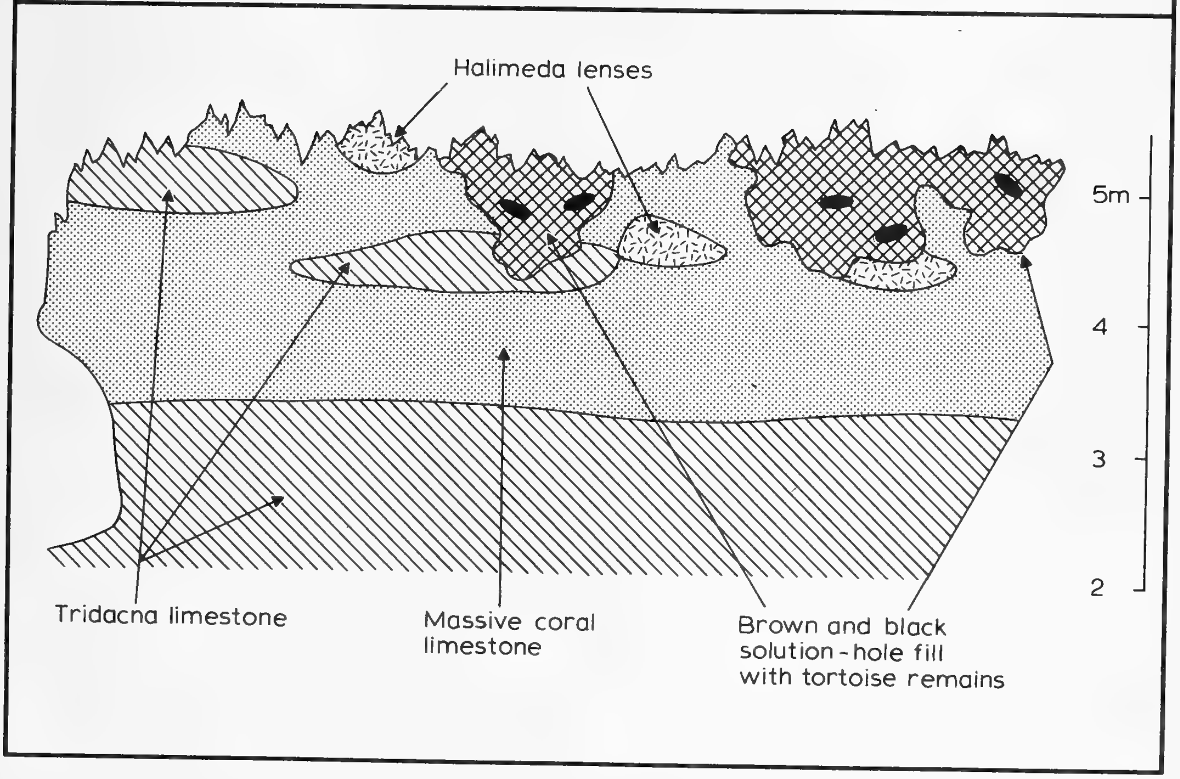


Figure 5. Section in the reef-limestone outcrop of Cap Vert

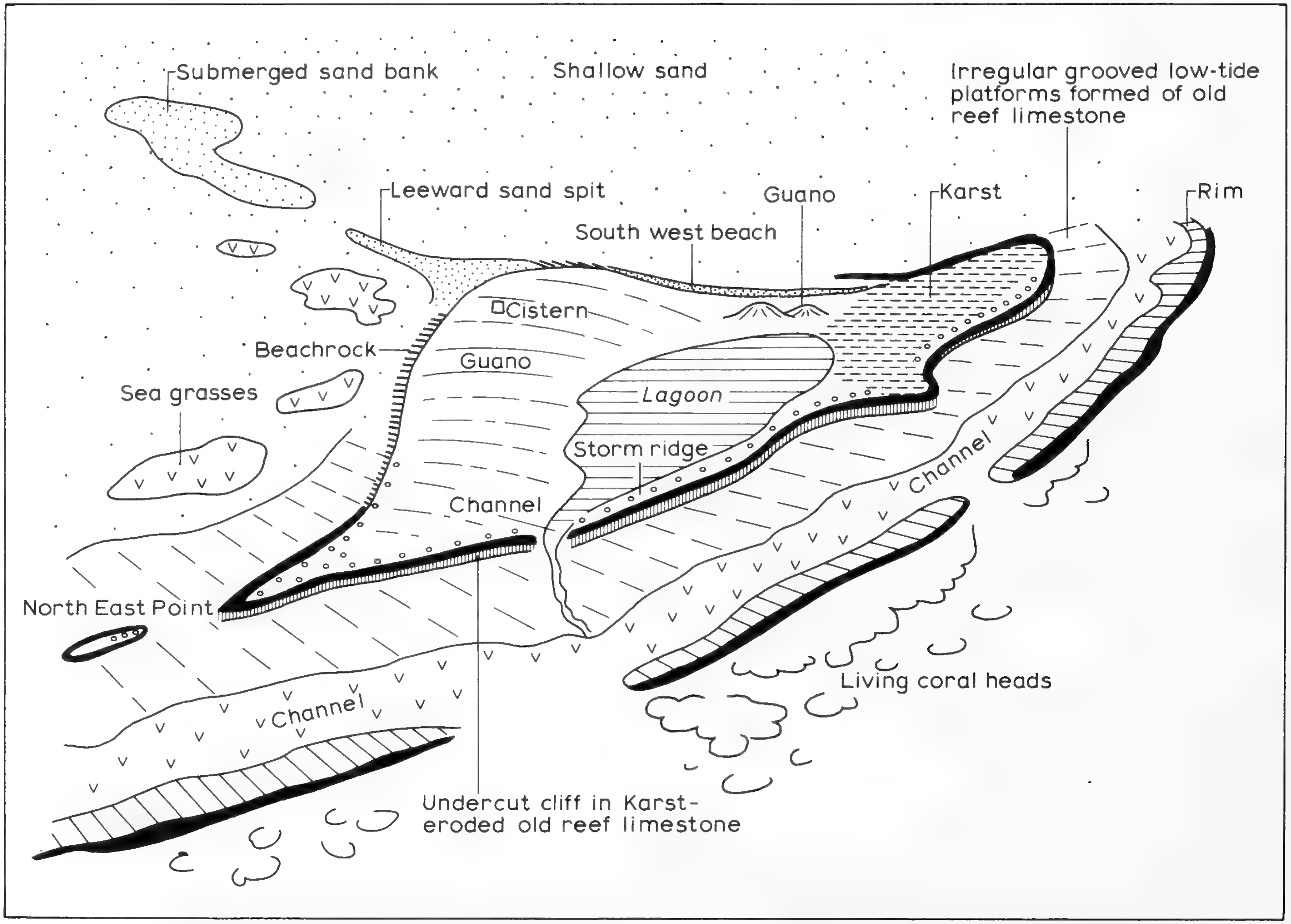


Figure 6. Geomorphic sketch of Ile du Lys (oblique view from an aerial photograph from the NNE taken by R. Battistini)

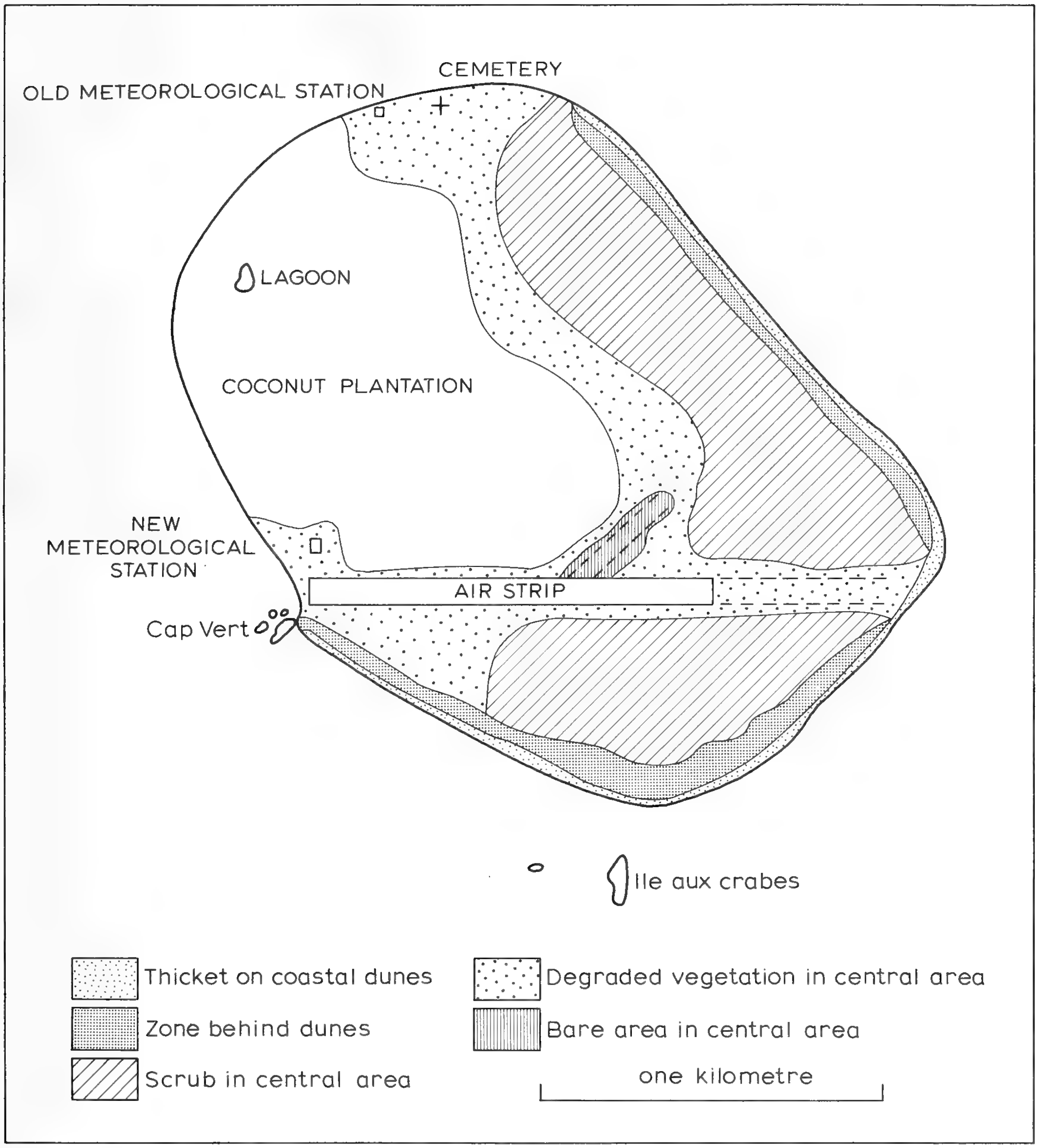


Figure 7. Sketch-map showing vegetation distribution on Grande Glorieuse

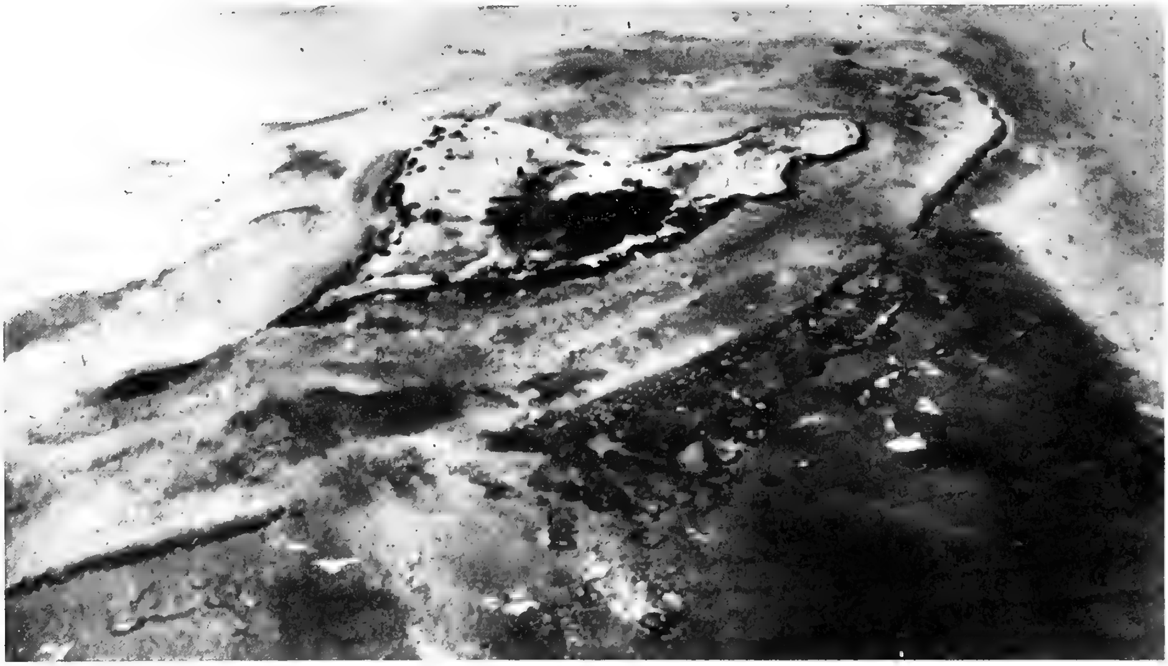


Plate 1. Ile du Lys from the northeast (oblique air photograph by R. Battistini)

Plate 2. Southwest part of Grande Glorieuse (oblique air photograph by R. Battistini)

Plate 3. South coast of Grande Glorieuse, eroded by Cyclone Félicie. Shrubs of *Scaevola taccada* and *Cordia subcordata* (photo R. B.)

Plate 4. Vegetation on the southern part of Grande Glorieuse: *Scaevola taccada* covered with the parasitic vine *Cassytha filiformis* (photo R. B.)

Plate 5. Ile aux Crabes: coral limestone at the base, covered with bedded detrital limestone, and above this a storm ridge of large boulders. Vegetation of *Pemphis acidula* (photo R. B.)

Plate 6. Mushroom rock and outer rubble ridge. On the horizon the rocks of Cap Vert (photo R. B.)

Plate 7. North coast of Ile du Lys. Foreground: the karst-eroded high-tide platform; background: the low-tide platform with large grooves, the channel, and the outer ridge encrusted with calcareous algae (photo R. B.)

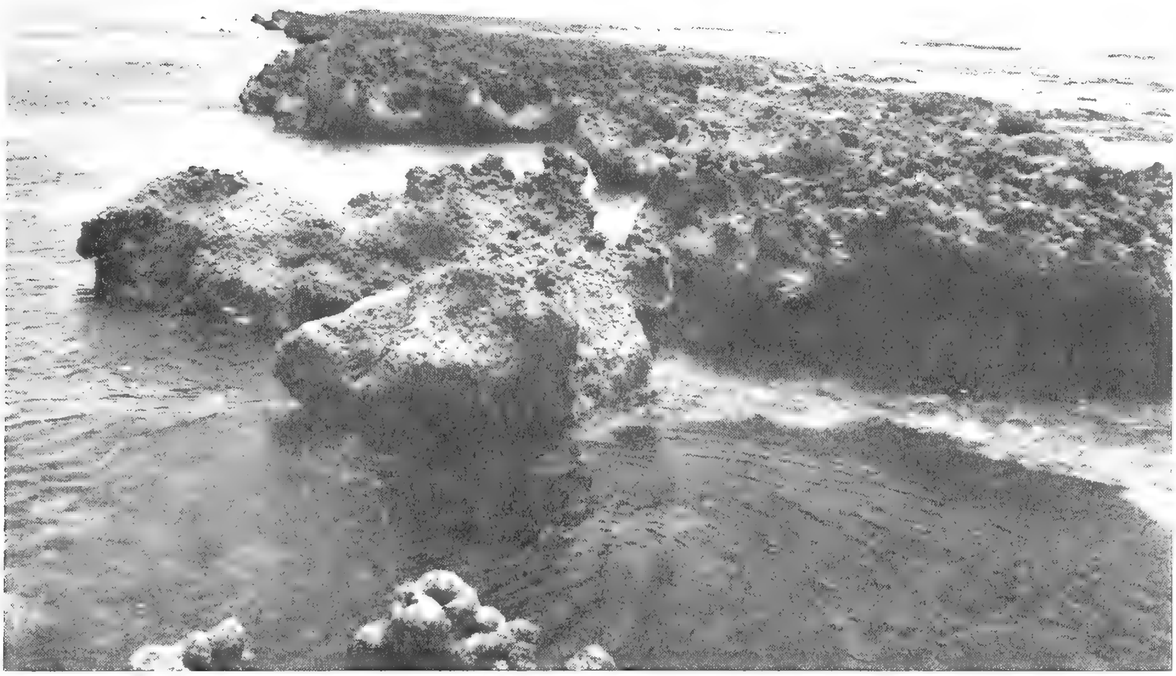


Plate 8. Ile du Lys: the outer ridge encrusted with calcareous algae (Photo R. B.)

Plate 9. Ile du Lys: karst-eroded surface in the extreme northwest, on the bedded *Halimeda* limestones. In the background, the west beach (photo R. B.)

Plate 10. Ile du Lys: basal coral limestone overlain by bedded *Halimeda* limestone, eroded into a projecting visor overlooking the low-tide platform. In the background, the outer ridge (photo R. B.)

Plate 11. Ile du Lys: the inner pool seen from the southern guano area. Bushes of *Pemphis acidula* round the pool (photo R. B.)

Plate 12. East coast of Ile du Lys: storm beach overlying old bedded detrital rocks. In the background, a seasonal sandspit (photo R. B.)

Plate 13. Grande Glorieuse: depression inland from the dunes, with *Fimbristylis abbreviata*, at the foot of dunes covered with *Cordia subcordata, Guettarda speciosa* and *Scaevola taccada.* In the depression one can see traces of lines of dunes now eroded (photo G. Cremers)

Plate 14. Young tuft of *Fimbristylis abbreviata* on Grande Glorieuse (photo G. Cremers)

Plate 15. Old tuft of *Fimbristylis abbreviata* on Grande Glorieuse (photo G. C.)

Plate 16. Scrub in the centre of Grande Glorieuse, with *Tournefortia argentea* and *Scaevola taccada* (photo G. C.)

Plate 17. Zone of *Tournefortia argentea* on the south coast of Ile du Lys (photo G. C.)

Plate 18. Central area of Ile du Lys, with completely dessicated *Boerhavia* sp. In the background, dome-shaped *Tournefortia argentea* (photo G. C.)

Plate 19. Ile du Lys: small pool open to the sea, with numerous bushes of *Pemphis acidula* (photo G. C.)

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No. 160

REEF ISLANDS OF RAROTONGA

by D. R. Stoddart

LIST OF VASCULAR FLORA

by F. R. Fosberg

Issued by
THE SMITHSONIAN INSTITUTION
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December 31, 1972

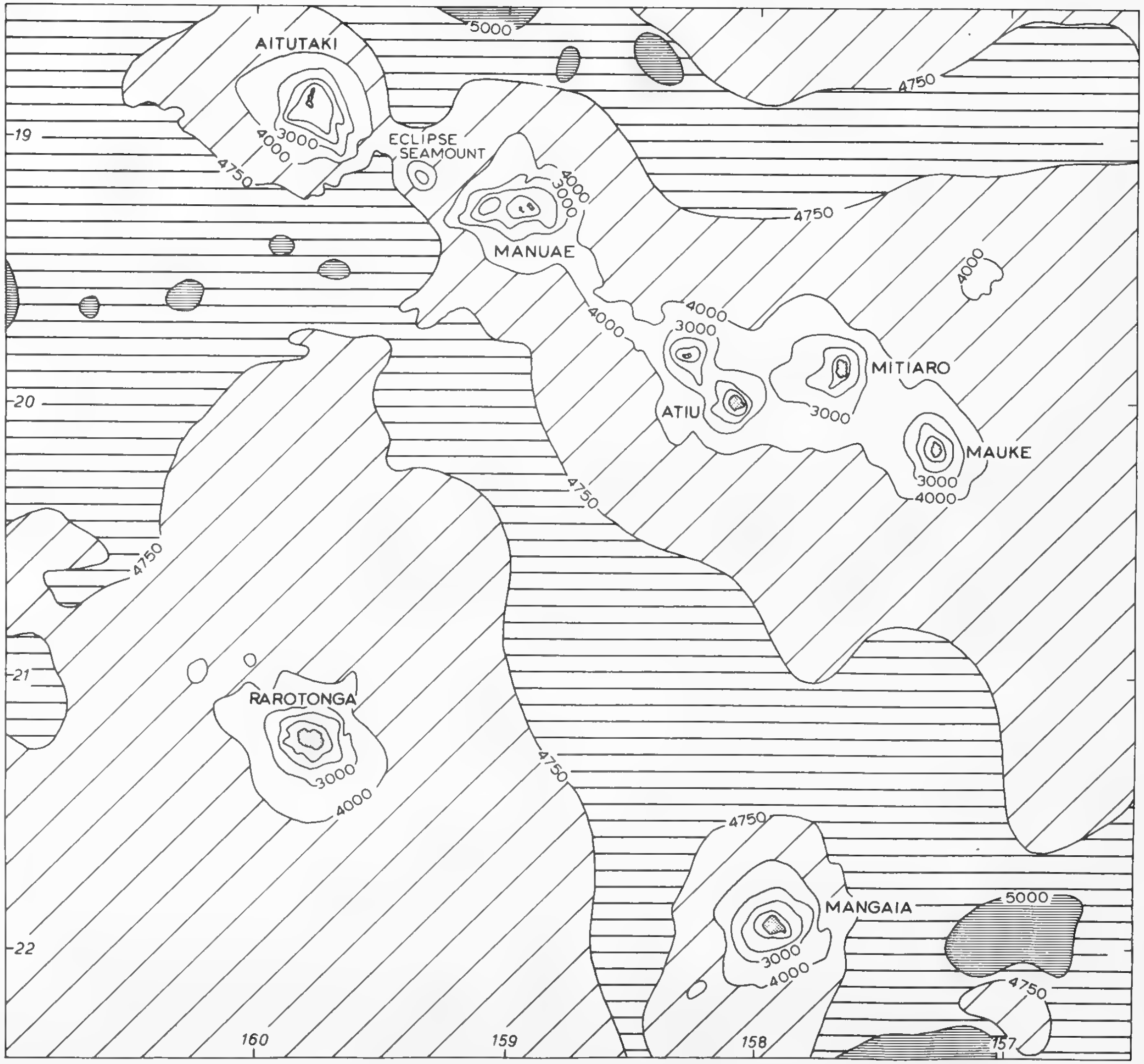

Figure 1. Bathymetry of the Southern Cook Islands. Based on Summerhayes (1967)

REEF ISLANDS OF RAROTONGA

by D.R. Stoddart

INTRODUCTION

Remarkably little is known of the coral reefs of Rarotonga, southern Cook Islands. Crossland (1928a, 616-619) and Davis (1928, 407-408) gave brief descriptions following short visits, and remarks on reef structure in the context of the geological history of the island have been made by Marshall (1908, 1912, 1930) and later workers (Wood, 1967).

A marine biology party from the Cook Bicentenary Expedition to the Southwest Pacific worked on Rarotonga from 21 to 27 August 1969. The party consisted of Dr. H.G. Vevers (Zoological Society of London), Dr. P.E. Gibbs (The Marine Laboratory, Plymouth), and the author. After a reconnaissance of the coast of Rarotonga, work was concentrated at Ngatangiia Harbour on the east side of the island, though some collections were also made at other localities. Subsequently the Ngatangiia area was also visited by Prof. W.R. Philipson (Department of Botany, University of Canterbury, Christchurch, New Zealand), during floristic studies carried out on the same expedition, and some of his results are used here.

The present paper gives a general description of the reefs and environment of Rarotonga, a detailed account of the reef islands of Ngatangiia, and a list of the vascular flora of the islands determined by Dr. F.R. Fosberg (Smithsonian Institution). Other results of the Ngatangiia work will appear elsewhere. A preliminary account of coral reef studies in the Cook Islands during the 1969 expedition has already been published (Gibbs, Stoddart and Vevers, 1971).

REEF GEOMORPHOLOGY

Rarotonga (latitude 21°12'S, longitude 159°46'W) is an isolated volcanic island, now deeply dissected by erosion, with a maximum altitude of about 640 m. It rises from the ocean floor at a depth of about 4000 m (Summerhayes and Kibblewhite, 1967), at which depth the volcanic cone is 45-55 km in diameter (Figure 1). The present island has maximum dimensions of 11.5 x 8 km. The exposed volcanics consist of basaltic and phonolitic eruptives; the latter have been dated radiometrically at 2.3-2.8 million years, indicating a Pliocene age for the uppermost lavas of the cone (Tarling, 1967). The volcanics are surrounded at the coast by a low apron of gravels and sands (Fig. 2). The gravels (Nikao Gravels) were deposited first and slightly cliffed before the deposition of the more recent Aroa Sands (Wood, 1967). Swamp deposits in places occupy gaps between the gravels and the beach ridges of the Aroa Sands, particularly along the south and west coasts. Small areas of elevated reef limestone outcrop in places round the coast, and may be extensive beneath the Aroa Sands; their significance will be discussed later.

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The island is surrounded by a fringing reef about 400 m wide along the south and 200 m wide along the west and north coasts. In Ngatangiia Harbour the reef edge lies about 1 km from the coast. The reef edge is continuous except for steep-sided narrow inlets at Avatiu and Avaroa on the north coast, Ngatangiia on the east, and several places on the south. The reef flats are planed-rock features, rarely carrying more than 1.5 m of water even at high tide; they are covered with sand sheets, and growing corals are not common. Marine phanerogams are absent. These flats are distinguished, especially at Ngatangiia Harbour, by extremely large populations of holothurians, with densities of *Holothuria atra* reaching up to 10 per sq m. An algal ridge is only weakly developed on the reefs, though Marshall (1930) states that it is higher in the south than the north.

Crossland (1928a, 616-619) considered that the reef was originally a barrier reef converted to a fringing reef by infilling of the lagoon by the coastal sands and gravels. He said little of the composition of the reef, except to note the existence of large brain corals and also of *Porites* heads in the boulder beach at Avarua (Crossland, 1928b, 721). Davis (1928, 407-408) rather misleadingly referred to Rarotonga's "close-set and little-eroded barrier reef, from a quarter to a half mile wide, now about 15 feet above sea level, enclosing a narrow lagoon flat or swamp"; he considered that the amount of sediment produced during dissection of the island, both before and during reef growth, required considerable subsidence for its disposal, and that this overall sinking of the island was to be distinguished from the more recent 5 m uplift of what he termed the barrier reef, and the subsequent infilling of its lagoon.

Ngatangiia Harbour on the west coast forms the most pronounced coastal indentation. Rarontonga's largest river, the Avana, flows into the harbour and discharges by the deep reef gap north of Motutapu (Fig. 3). Outcrops of elevated reef limestone are found on both sides of the harbour entrance. The Harbour islands, from Motutapu southwards, continue the general trend of the coast (though Taakoka is volcanic, not detrital). Wood (1967) maps the detrital islands as Aroa Sands, and both Marshall (1930) and Wood (1967) draw attention to the absence of sands and gravels on the mainland coast of Ngatangiia Harbour, where volcanic rocks reach the sea. Marshall (1930, 19-20) proposed that the detrital islands represented fragments of a formerly continuous beach ridge breached by hurricanes, with as a result the sea flooding the swampy former back-ridge area.

ENVIRONMENT

Rarotonga lies in the South-east Trade Wind belt. There are no climatic data for the Ngatangiia area, on the windward, wetter side of the island. Avarua, on the leeward side, has a mean annual rainfall of about 2050 mm, though with considerable variation between years. Most of the rain falls during March, April and May; and the driest months, with less than 100 mm average, are July and September. Mean annual temperature is 23.6°C. Highest recorded temperature near sea level at Avarua is 33.5°C, and lowest 8.9°C (Marshall 1930; Grange and Fox 1955).

The island is frequently affected by storms of hurricane intensity, generally approaching from the northwest. Major recorded storms are those of December 1831, December 1842, March 1846 (especially damaging at Ngatangiia), December 1848, March 1926, March 1943, January 1944, January 1946, December 1948, and September 1950 (Gill, 1885; Marshall, 1930; Hutchings, 1953), but this list is clearly incomplete. Because of the open-ocean situation, storm surges associated with hurricanes are not important; most of the effects are from wind and wave activity. Tsunamis also occasionally occur. Those of May 1960 resulting from the Chilean earthquakes reached the comparatively low height in inlets at Rarotonga of 1.5 m above normal sea level, partly because the tide was low at the time and normal water level was below the outer reef edge (Keys, 1963). Both hurricanes and tsunamis, however, are likely to have been significant controls in the development of the reef islands.

Tides are semi-diurnal, with a rather pronounced diurnal inequality at and following neaps. According to predictions prepared by the Hydrographic Department, Ministry of Defence, London, for the expedition, in 1969, the range at springs is 0.85 m and at neaps 0.33 m.

DESCRIPTION OF THE ISLANDS

Motutapu (Fig. 4)

Motutapu is the northernmost and largest of the Ngatangiia islands: it is 600 m long, 360 m wide, with an area of 11 ha. The northern part of the island consists of a rough *makatea* or elevated reef limestone, well cemented, with a local relief of up to 1 m though with a rather subdued erosional topography (Plate 1); it is cliffed and undercut at intertidal levels, and its upper surface stands at 2-3 m above the sea (Plate 2). A small patch of similar rock outcrops further south on the seaward shore, and much of the northeastern part of the island is presumably underlain by this limestone. At the north point the *makatea* directly overlooks the deeper water of the harbour entrance, and similar rock outcrops on its northern side.

Apart from the *makatea* the island is a simple cay, with a gravel and cobble ridge and intertidal storm rubble forming a beach up to 5 m high on its seaward side (Plate 3), and a wide intertidal expanse of fine sand and silt forming an *Uca*-dominated flat on its leeward side. The seaward beaches are 25-30 m wide; those on the lee side are narrower as well as lower. All are aggrading except for a cliffed sector of cobble beach on the north coast.

The vegetation of the *makatea* differs from that of the rest of the cay. *Sesuvium portulacastrum* covers the floors of potholes, with a low scrub of *Wedelia biflora* and *Capparis cordifolia*. *Heliotropium anomalum* and *Ipomoea pes-caprae* are also present. Most of the characteristic strand plants of the sand cay are absent.

On the seaward coast of the sand cay section there is a long narrow zone of *Scaevola taccada*, with some scattered bushes of *Tournefortia argentea* and a patch of *Lantana camara*. Outpost vegetation is restricted to small areas of *Vigna marina* and *Cassytha filiformis*. The *Scaevola*, in places up to 4 m tall, is replaced inland by a dense woodland of *Hibiscus tiliaceus* 6-8 m tall, with some *Guettarda, Morinda, Casuarina,* and occasional conspicuous tall coconuts. The interior of the cay is occupied by a higher woodland, dominated by coconuts, with *Hernandia sonora, Leucaena insularum, Morinda citrifolia, Carica papaya* and other species. On the low-lying, partly waterlogged lee shore there are areas of grass and sedge marsh dominated by a sterile grass (possibly *Paspalum*) and inhabited by *Uca*.

Oneroa (Fig. 5)

Oneroa, south of Motutapu, is slightly smaller; it lacks the *makatea* but is otherwise similar in topography and vegetation. The island is 500 m long and 200-250 m wide, with an area of 10.6 ha.

The seaward beach (Plate 4) consists of sand, gravel and cobbles, with broken coral rubble at its foot and strewn across its surface; the coarser sediments are more common in the southeast. The beach is 20 m wide and 2-3 m high. The leeward beach is low and sandy, with a sand spit 100 m long extending lagoonward in the north. This spit encloses, as at Motutapu, a wide intertidal flat of sand and fine gravel with large numbers of *Uca*. Cemented rubble forms a low shelf at the foot of the seaward beach towards the north, but otherwise there is no beachrock.

The main vegetation of the island is a mixed woodland dominated by *Casuarina*, broadleaf trees and coconuts. *Hibiscus tiliaceus* is an important component, together with *Hernandia sonora, Pisonia grandis, Morinda citrifolia* and *Leucaena insularum*. Several species of ferns

form a ground cover. *Casuarina* reaches the shore in several places, and is locally being undermined by beach erosion. *Scaevola taccada* forms an interrupted beach-crest scrub up to 4 m tall, with some *Tournefortia* and *Guettarda,* on the seaward shore. Inland from the narrow *Scaevola* belt is a zone of taller *Pisonia* and *Hernandia* woodland 40-50 m wide, largely growing on coarse beach-crest coral rubble with no other ground cover. At the abrupt inner edge of the rubble spread, on sand and fine gravel, the vegetation changes to a mixed woodland dominated by *Casuarina* with a ground cover of ferns and grasses. The *Scaevola* belt is wider and more continuous on the lagoon shore, again with occasional *Tournefortia; Sophora* and *Suriana* are represented by isolated bushes. Outpost species on the beach outside the *Scaevola* zone include *Cassytha, Cenchrus* and *Triumfetta.*

Koromiri (Fig. 6)

Koromiri, the smallest of the cays (320 m long, 120 m wide, area 3 ha) strikingly resembles Oneroa in its topography, with a prominent northern sand spit. The beaches are narrower, however, and on the southeast coast cliffed and retreating. The island is distinguished by its relict beachrock extending up to 120 m seaward of the cay.

Apart from patches of *Hernandia, Hibiscus, Morinda* and *Guettarda* woodland, the island is covered with *Casuarina* woodland. Beach-crest scrub of *Scaevola taccada,* with some *Tournefortia argentea,* is most continuous on the lagoon shore, where *Cassytha* is abundant. Outpost vegetation is very limited, with some *Vigna marina* and *Triumfetta procumbens.*

Taakoka

Taakoka, the southernmost island, set well back from the reef edge, is not a sand cay but a low hill of basalt forming an island half the size of Koromiri. The island may be described in two parts. First, a central plateau, consisting of a jumble of large angular and sub-rounded basalt blocks, encrusted with lichens and covered with bryophytes, and surrounded on its seaward margins by large spreading trees of *Barringtonia asiatica* 10-15 m tall. In the centre of the plateau there are some 50 coconut trees 15-25 m tall, with *Morinda, Hernandia* and ferns. The plateau stands about 6 m above sea level. Second, there is a "tail" lagoonward of the plateau, of basalt blocks up to 1 m long. This has an outer zone of *Casuarina* up to 20 m tall, with *Vigna marina* and *Ipomoea macrantha* beneath, and an inner zone of *Hernandia,* 10 m tall, with *Morinda,* coconuts and ferns.

Scaevola grows abundantly among the basalt blocks of the seaward coast, with *Wedelia biflora, Vigna marina* and *Ipomoea pes-caprae.* Along the north and south shores *Barringtonia* approaches close to the beach, with thickets of *Hibiscus tiliaceus* and outpost *Vigna marina* and *Ipomoea macrantha.*

Several species are clearly introduced, though the island is not inhabited. These include not only the coconuts, but cultivated *Hibiscus* and *Hippeastrum,* and a single banana plant.

It is clear that Taakoka, so different physiographically, has little in common with the other three islands, and is only linked with them by proximity. Along the north shore there is a thick outcrop of beachrock, consisting of angular basalt cobbles in a red clayey matrix which is presumably a decomposition product of the basalt. The beach sands, as on the other islands, are, however, reef-derived.

DEVELOPMENT OF THE ISLANDS

From these surveys of the cays, it is not possible to confirm Marshall's proposal (1930, 19-20) that the islands form part of a formerly continuous ridge of Aroa Sands fragmented by storm action. This could be so, but equally the islands have all the characteristics of ordinary sand cays, and they show no obvious signs of major erosion or dissection. Nor is there any evidence between the islands, e.g. in relict beachrock, of formerly more continuous land. The islands, other than Taakoka, consist of successive increments of storm-deposited rubble and cobbles of reef origin on the seaward beaches, with infill and spit-growth of fine gravel and sand to leeward. It seems likely that these processes of aggradation are still active. The islands in their present form are not therefore directly related to the occurrence of raised reefrock remnants in the *makatea* of Motutapu and the mainland coast. There are also two small islands on the northern reef flats of Rarotonga: one near Avatiu has been much altered by land reclamation on the reef flat, but the other, Motu Toa, has probably also originated by sediment accretion to form a discrete island on the reef flat.

Some data are available on the absolute chronology of late Pleistocene and Holocene events at Rarotonga. Schofield (1970) has published C^{14} dates on *makatea* samples: a sample from Ngatangiia Harbour, elevation 3.05 m, is dated at 28,200 ± 850 yr B.P., and one at Te Ara Vaka, elevation 1.83 m, at more than 48,900 yr. A sample from 3.2 m elevation at Matavera could not be dated. Schofield suggests that the reef from which these samples were taken (equivalent to the Motutapu *makatea*) was formed during an interstadial at 32,000–35,000 yr B.P.; it is perhaps more probable, in view of the difficulty of dating such material, that it correlates with the *makatea* of Mangaia, for which Veeh (1966) obtained a uranium-series age of 110,000 ± 50,000 yr.

There is some evidence from Rarotonga for much more recent high stands of the sea. A raised reef at Avarua on the north coast, at 1 m above present low water level, with corals in the position of growth, has been dated at 2030 ± 60 yr B.P., and soil samples from beach ridges of Aroa Sands age have been dated at 1235 ± 57, 2470 ± 63, and 3510 ± 50 yr B.P. (Wood 1967; Schofield 1970). Schofield also reports a beachrock at Titikaveka at 1 m above present high water level. He suggests that these recent dates indicate sea stands at +2 and +1 m above the present, and that the Aroa Sands beach ridges, which rise to about 8 m above present sea level, were formed during these higher stands. There is no evidence of such stands in the topography of the Ngatangiia reef islands, and indeed large parts of the islands would be submerged with such higher sea levels. It should be noted that the much older Motutapu *makatea* is tidally notched at present intertidal levels, and there are no apparent signs of higher notches.

The Ngatangiia islands can thus be assumed, from their own characteristics, to have had a simple aggradational history, punctuated by hurricane events, accumulating on reef flats partially formed by the erosion of older elevated reef limestone. It is possible that they are younger than the sea-level events described by Schofield, or that the evidence of such events in the physiography of the islands has been erased by later storm action.

SUMMARY OF VEGETATION

The vegetation of the islands is relatively simple. Essentially it comprises a broadleaf woodland of *Hibiscus, Guettarda, Morinda, Pisonia* and *Hernandia,* with coconuts and *Casuarina,* the latter apparently spreading at the expense of broadleaf trees; a beach-crest scrub of *Scaevola taccada* with some *Tournefortia argentea;* and an outpost or pioneer strand vegetation, very patchily developed, of *Triumfetta, Ipomoea, Vigna* and other species. The Motutapu *makatea* has its own distinctive vegetation of *Wedelia biflora, Ipomoea, Heliotropium,* and *Capparis cordifolia.* Ill-drained leeward sand flats have a low vegetation of grasses and sedges. This restricted range of vegetation types reflects the limited range of habitats and the

small size of the islands, as well as floristic poverty. Some types, notably *Barringtonia* woodland, are found only on Taakoka and not on the sand cays.

There is no mangrove vegetation, and sea-grasses are absent, not only on Rarotonga but throughout the Cook Islands. Some species, especially littoral shrubs, are surprisingly rare, particularly *Suriana maritima*, which is extremely common on Aitutaki on similar cays. Wilder (1931) recorded this species as occurring only on Motutapu; it was not seen there in 1969, but a single specimen was growing on Oneroa.

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LIST OF VASCULAR PLANTS

by F.R. Fosberg

Plants collected in 1969 and determined by Dr. F.R. Fosberg, together with those collected on the cays by Prof. W.R. Philipson, comprise 2 bryophytes (not determined), 1 lichen (not determined), and 49 species of vascular plants, including 4 species of ferns. Some earlier records, usually without precise location, are given in the floras of Cheeseman (1903) and Wilder (1931). One species recorded on Motutapu by Wilder, *Myoporum sandwicense* A. Gray, was not collected in 1969.

Of the plants in the following list, excluding ferns, 26 species are recorded from Motutapu, 17 from Oneroa, 14 from Koromiri, and 18 from Taakoka. Seven of the Taakoka species, plus one fern, are recorded only from that island and not from the three reef islands, bringing the number of species from the latter down to 41.

The list is interesting for its omissions, compared with other Cook Island reef islands, particularly those of Aitutaki. There are no pandans; *Pemphis acidula,* elsewhere abundant, is missing; and there are no species of Euphorbiaceae, though on similar islands on Aitutaki *Euphorbia chamissonis* is an important component of the vegetation.

Some aspects of the floristics of Rarotonga are discussed by Philipson (1971).

Almost complete sets of the specimens cited are deposited in the U.S. National Herbarium, Washington, D.C. and in the herbarium of the Botany Division, Dept of Scientific and Industrial Research, Christchurch, New Zealand.

POLYPODIACEAE

Asplenium nidus L.
Oneroa: *Stoddart 2118.* Koromiri: *Stoddart 2154.*

Davallia solida (F. f.) Sw.
Oneroa: *Stoddart 2119.* Taakoka: *Stoddart 2167.*

Nephrolepis hirsutula (Forst. f.) Presl
Taakoka: *Stoddart 2169.*

Polypodium scolopendria Burm. f.
Oneroa: *Stoddart 2121.* Koromiri: *Stoddart 2157.* Taakoka: *Stoddart 2168.*

GRAMINEAE

Cenchrus echinatus L.
Oneroa: *Stoddart 2158.*

Lepturus repens R. Br.
Taakoka: *Philipson 10349.*

Stenotaphrum secundatum (Walt.) O. Ktze.
Oneroa: *Philipson 10354.*

Thuarea involuta (Forst.) R. Br. ex R. and S.
Motutapu: *Stoddart 2135.*

CYPERACEAE

Fimbristylis cymosa R. Br.
Motutapu: *Philipson 10364.*

PALMAE

Cocos nucifera L.
Motutapu: Stoddart, sight record. Oneroa: Stoddart, sight record. Koromiri: Stoddart, sight record. Taakoka: Stoddart, sight record.

AMARYLLIDACEAE

Hippeastrum puniceum (Lam.) Voss
Taakoka: *Stoddart 2159.*

MUSACEAE

Musa sapientum L.
Taakoka: Stoddart, sight record.

CASUARINACEAE

Casuarina equisetifolia L.
Motutapu: Stoddart, sight record. Oneroa: *Stoddart 2115.* Koromiri: Stoddart, sight record. Taakoka: Stoddart, sight record.

PIPERACEAE

Peperomia leptostachya H. and A.?
Motutapu: *Stoddart 2140.*

Peperomia pallida var.
Oneroa: *Philipson 10360.*

NYCTAGINACEAE

Pisonia grandis R. Br.
Oneroa: *Stoddart 2114.*

AIZOACEAE

Sesuvium portulacastrum L.
Motutapu: *Stoddart 2105; Philipson 10365.*

PORTULACACEAE

Portulaca lutea Sol. ?
Motutapu: *Stoddart 2106.*

LAURACEAE

Cassytha filiformis L.
Motutapu: Stoddart, sight record. Oneroa: *Stoddart 2117.* Koromiri: Stoddart, sight record.

HERNANDIACEAE

Hernandia sonora L.
Motutapu: *Stoddart 2137.* Oneroa: *Stoddart 2124.* Koromiri: *Stoddart 2148.* Taakoka: *Stoddart 2164.*

CAPPARIDACEAE

Capparis cordifolia Lam.
Motutapu: *Stoddart 2141; Philipson 10361.* Koromiri: *Stoddart 2155.*

LEGUMINOSAE

Canavalia sericea A. Gray
Motutapu: *Stoddart 2133.*

Leucaena insularum (Lam.) Dän.
Motutapu: *Stoddart 2139.* Oneroa: Stoddart, sight record.

Mucuna gigantea (Willd.) DC.
Taakoka: *Philipson 10351.*

Sophora tomentosa L.
Oneroa: *Stoddart 2127.*

Vigna marina (Burm.) Merr.
Motutapu: *Stoddart 2112.* Koromiri: *Stoddart 2146.* Taakoka: *Stoddart 2165.*

SURIANACEAE

Suriana maritima L.
Oneroa: *Stoddart 2123.*

RHAMNACEAE

Colubrina asiatica (L.) O. Ktze.
Oneroa: *Stoddart 2131; Philipson 10356.*

TILIACEAE

Triumfetta procumbens Forst.
Oneroa: *Stoddart 2132.* Koromiri: *Stoddart 2147.*

MALVACEAE

Hibiscus sp. (cultivated variety)
Taakoka: *Stoddart 2161.*

Hibiscus tiliaceus L.
Motutapu: *Stoddart 2104.* Oneroa: *Stoddart 2130.* Koromiri: *Stoddart 2150.*
Taakoka: *Stoddart 2166.*

CARICACEAE

Carica papaya L.
Motutapu: *Philipson 10363.*

LECYTHIDACEAE

Barringtonia asiatica (L.) Kurz
Taakoka: *Stoddart 2172.*

MYRSINACEAE

Ardisia elliptica Thunb.
Motutapu: *Stoddart 2142.*

CONVOLVULACEAE

Ipomoea macrantha R. and S.
Taakoka: *Stoddart 2163.*

Ipomoea pes-caprae subsp. *brasiliensis* (L.) v. Ooststr.
Motutapu: *Stoddart 2108.* Taakoka: Stoddart, sight record.

BORAGINACEAE

Heliotropium anomalum H. and A.
Motutapu: *Stoddart 2113.*

Tournefortia argentea L. f.
Oneroa: *Stoddart 2128.* Koromiri: *Stoddart 2152.*

VERBENACEAE

Lantana camara L.
Oneroa: *Stoddart 2122.*

Lantana camara var. *aculeata* (L.) Mold.
Motutapu: *Stoddart 2110.* Taakoka: *Stoddart 2160.* Koromiri: *Philipson 10352.*

Stachytarpheta urticifolia Sims
Koromiri: *Stoddart 2153.*

Vitex trifolia L. var. *bicolor* (Willd.) Mold.
Motutapu: *Philipson 10362.*

RUBIACEAE

Guettarda speciosa L.
Motutapu: *Stoddart 2136.* Oneroa: *Stoddart 2116.* Koromiri: *Stoddart 2151; Philipson 10352.*

Morinda citrifolia L.
Motutapu: *Stoddart 2144.* Oneroa: *Stoddart 2126.* Koromiri: *Stoddart 2149.* Taakoka: *Stoddart 2170.*

GOODENIACEAE

Scaevola taccada (Gaertn.) Roxb.
Motutapu: *Stoddart 2145.* Oneroa: *Stoddart 2129.* Koromiri: Stoddart, sight record. Taakoka: *Stoddart 2171.*

COMPOSITAE

Bidens pilosa L.
Koromiri: *Stoddart 2156.*

Elephantopus mollis HBK.
Motutapu: *Stoddart 2143.*

Emilia sonchifolia (L.) DC.
Motutapu: *Stoddart 2134.*

Sonchus oleraceus L.
Motutapu: *Stoddart 2111, 2138.*

Wedelia biflora (L.) DC.
Motutapu: *Stoddart 2107.* Taakoka: *Stoddart 2162.*

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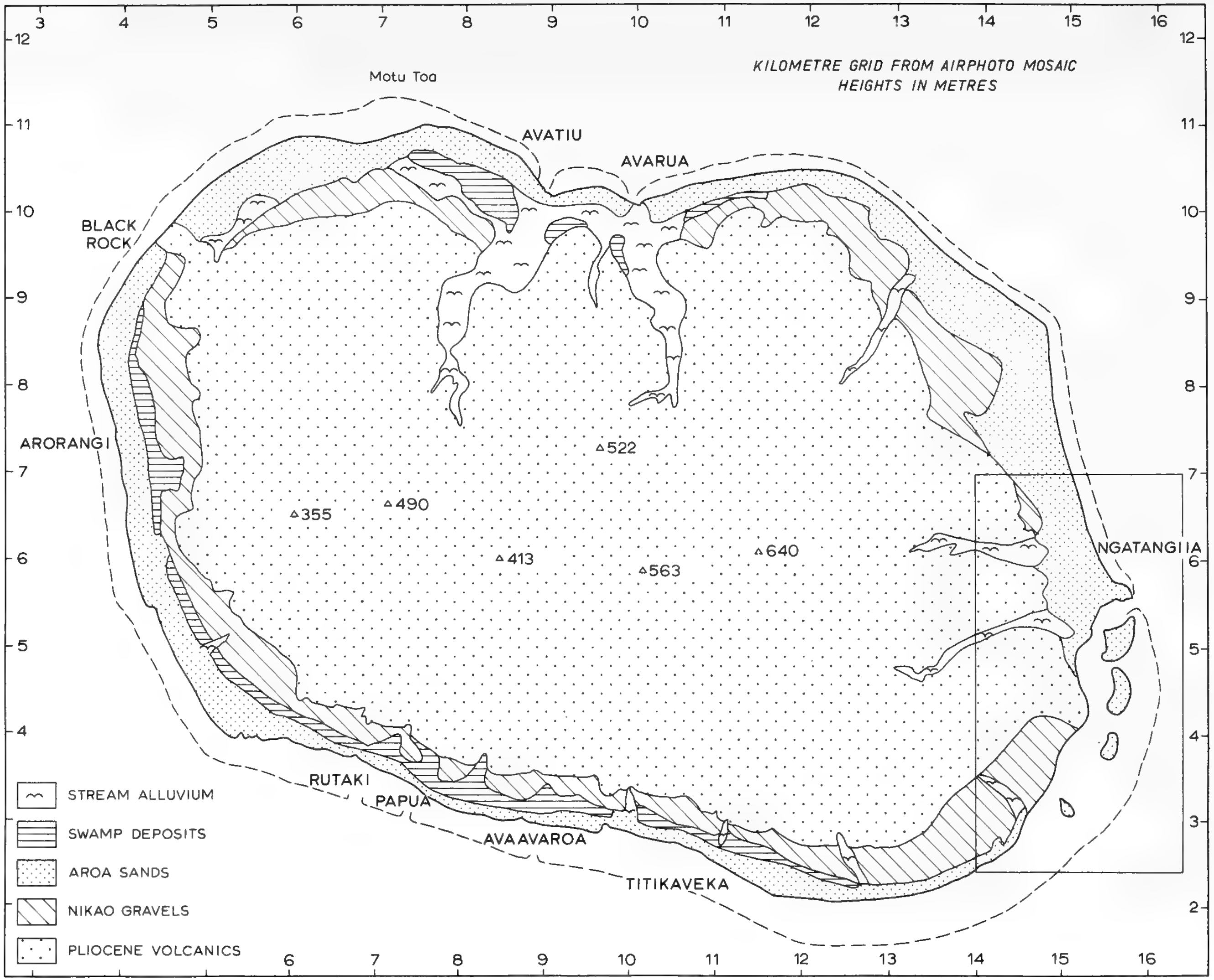

Figure 2. Geology of Rarotonga. After Wood (1967); topography reduced from air photograph mosaic

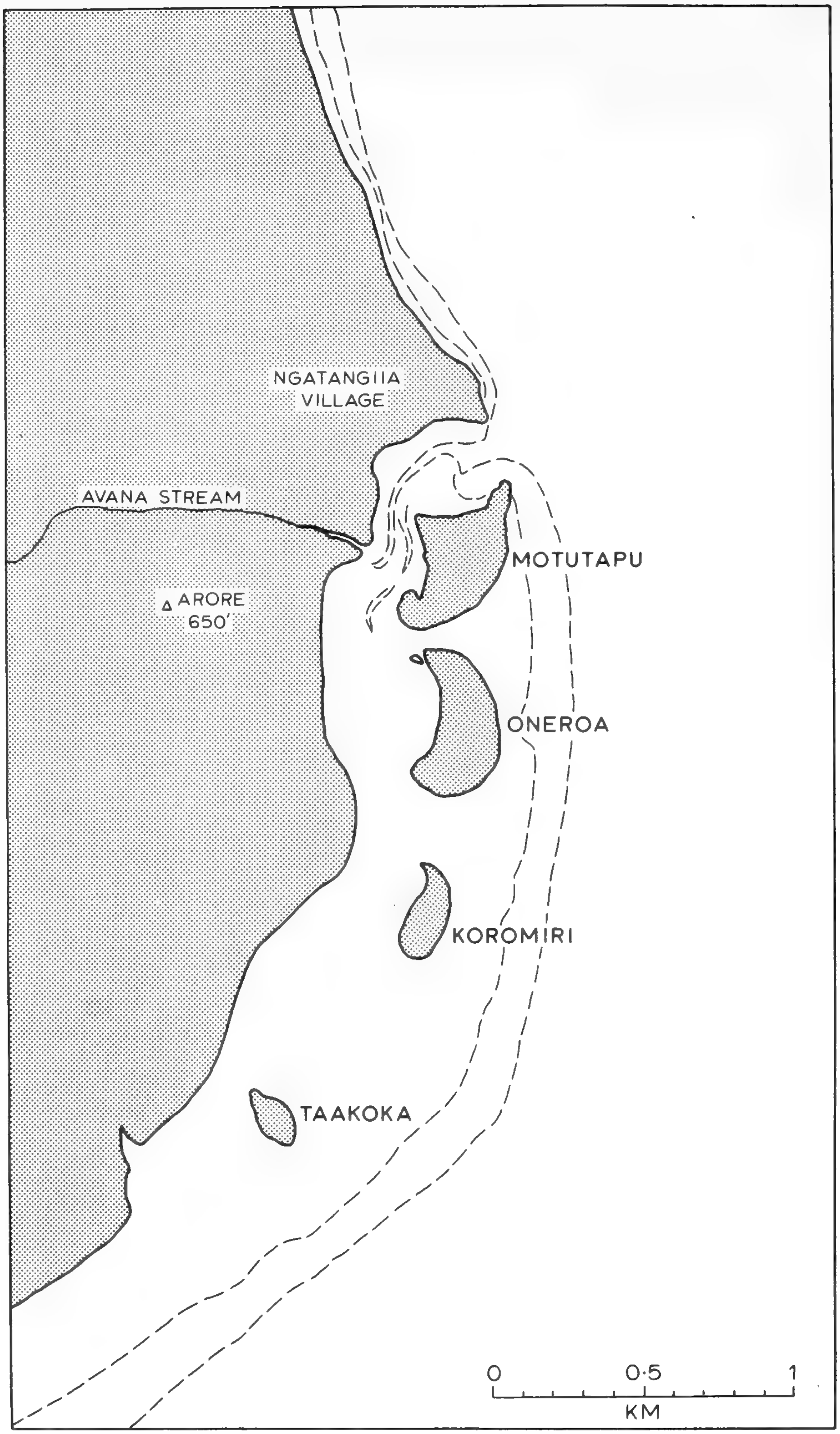

Figure 3. Reef islands of Ngatangiia Harbour.
For location, see Figure 2

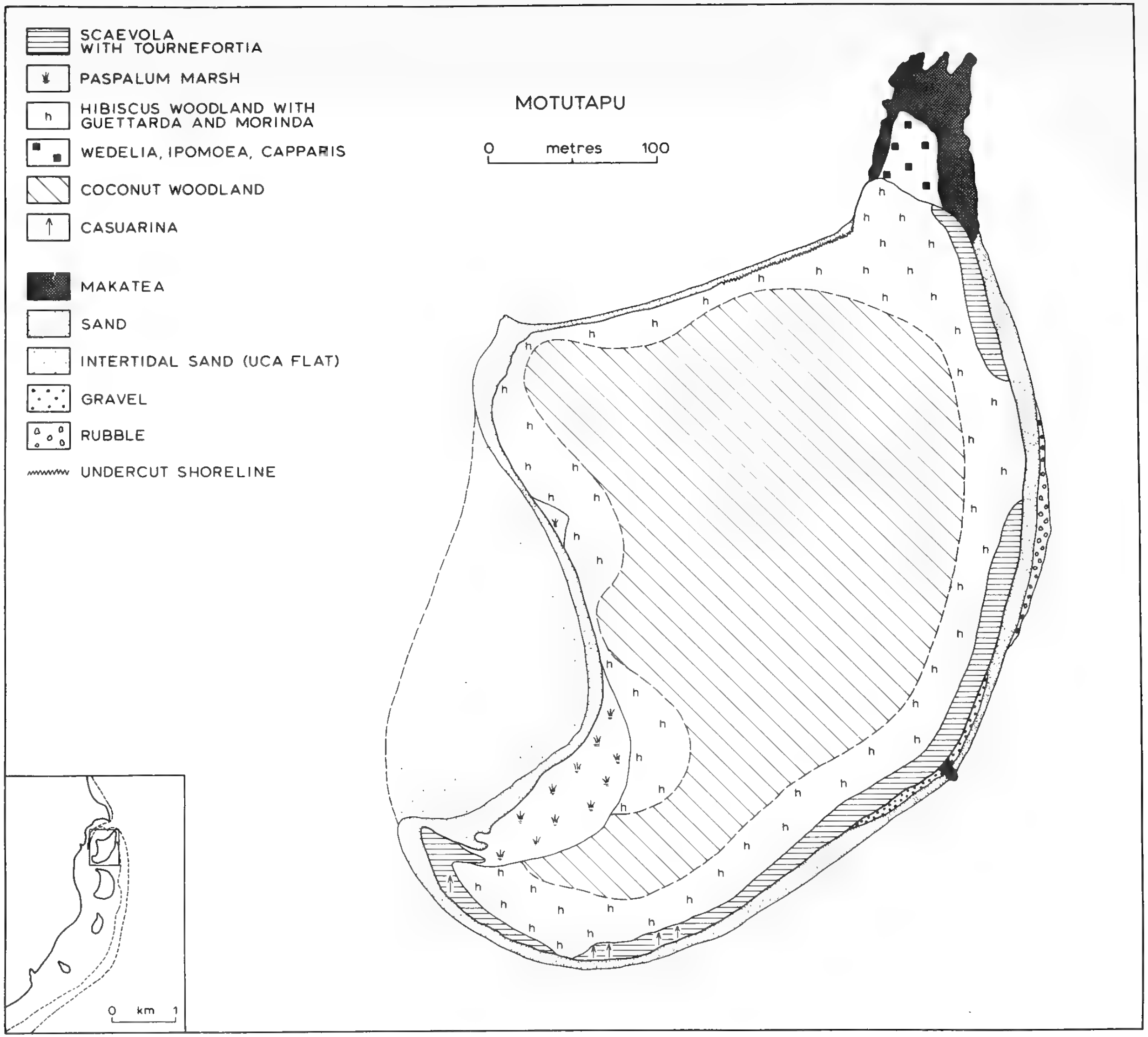

Figure 4. Motutapu

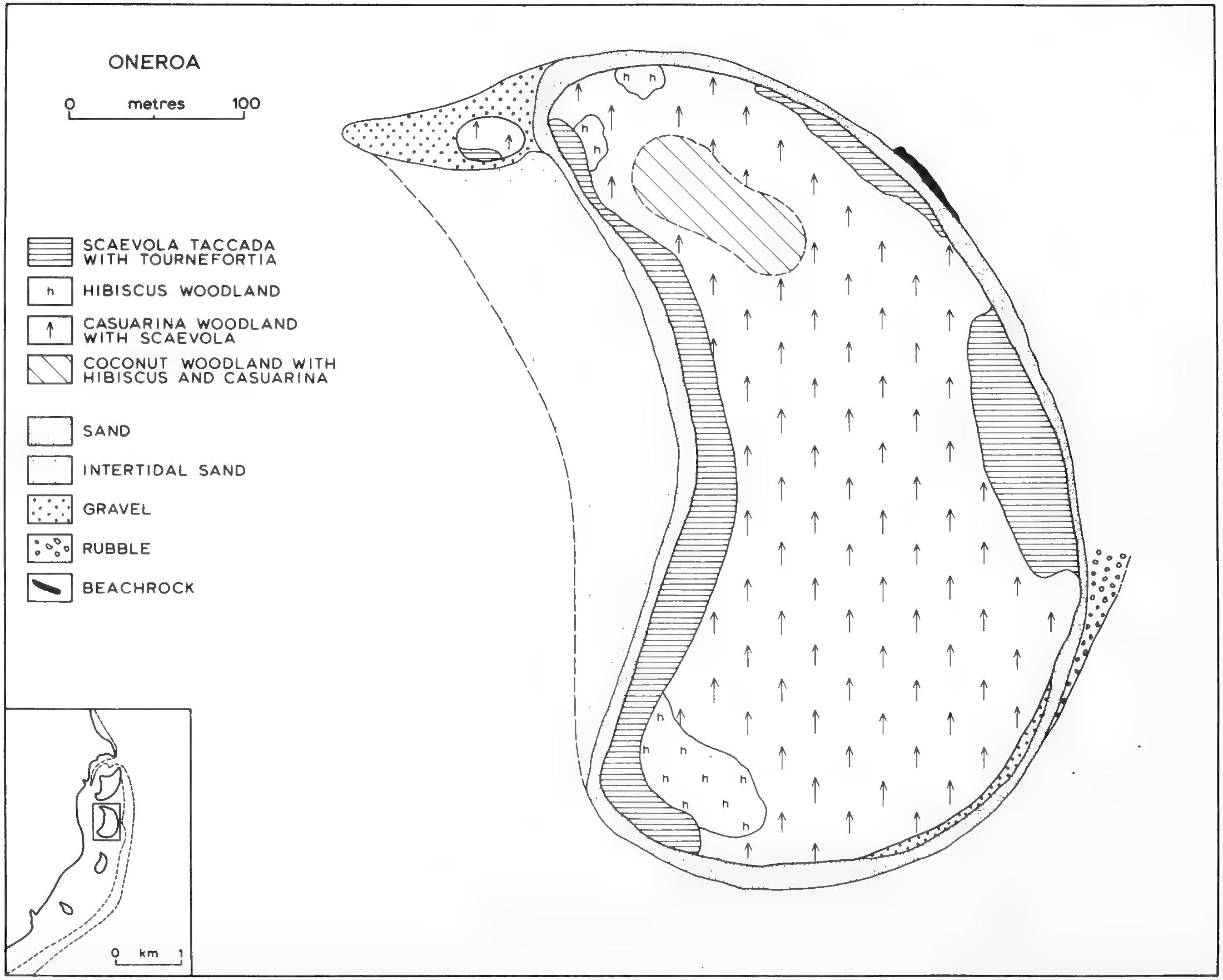

Figure 5. Oneroa

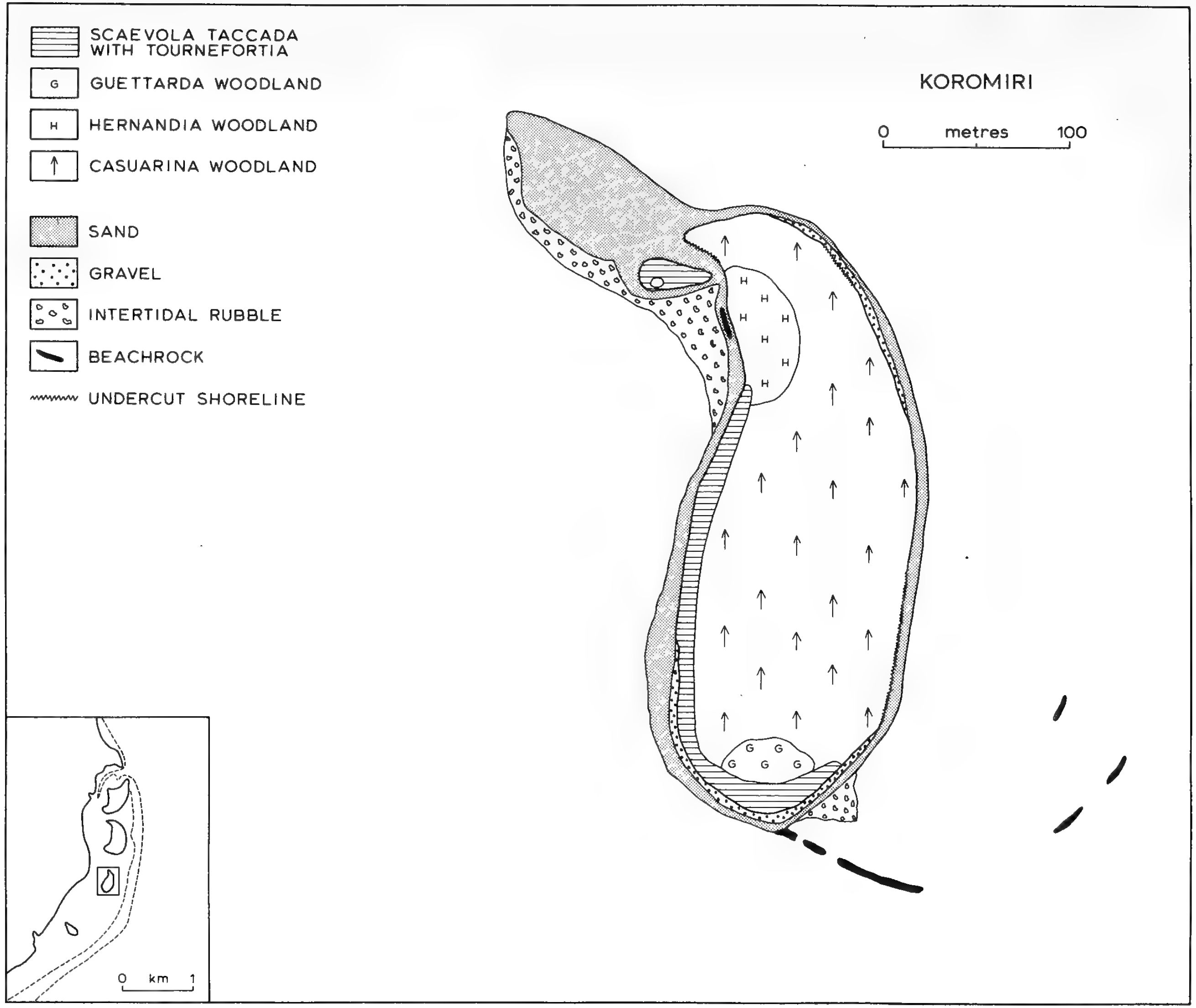

Figure 6. Koromiri

Plate 1. Dissected makatea surface on Motutapu

Plate 2. Makatea outcrop at the northeast point of Motutapu

Plate 3. Seaward cobble beach with littoral *Scaevola* scrub, Motutapu

Plate 4. Storm rubble on the southeast beach of Oneroa

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SOUTH INDIAN SAND CAYS

by D. R. Stoddart and F. R. Fosberg

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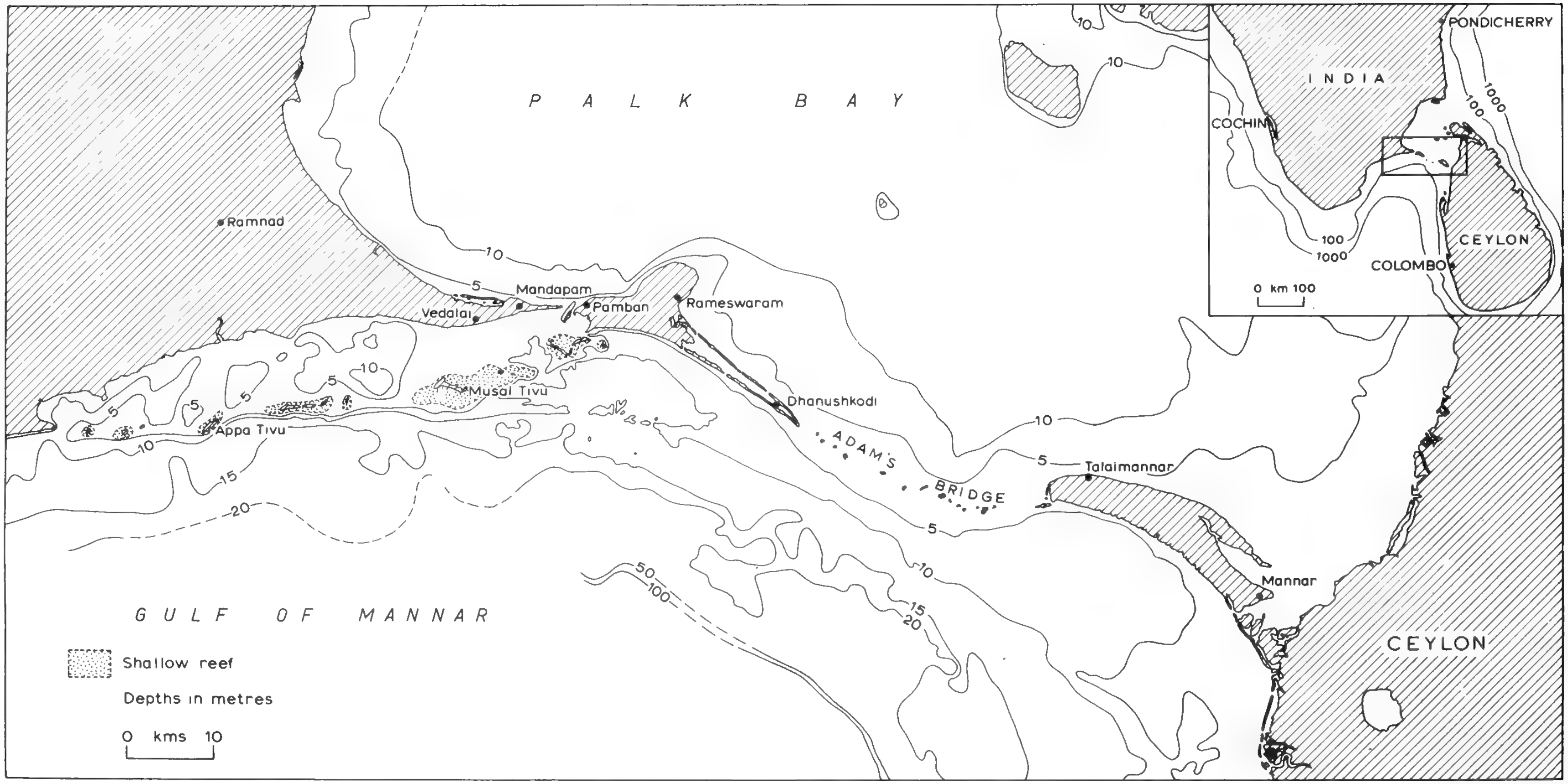

Figure 1. Adam's Bridge, between India and Ceylon, showing the location of the Gulf of Mannar reefs

SOUTH INDIAN SAND CAYS

by D.R. Stoddart and F.R. Fosberg

INTRODUCTION

Adam's Bridge and associated islands between India and Ceylon separate Palk Bay to the north, a shallow expanse of water 11-13 m deep, from the Gulf of Mannar to the south. A discontinuous barrier reef, here termed the Mannar barrier, parallels the mainland coast of India, round the northern side of the Gulf of Mannar, from Tuticorin to Pamban, a distance of 140 km. This barrier reef rises from a shelf less than 35 m deep but up to 25 km wide, from the edge of which the Gulf floor slopes steeply to depths of more than 300 m (Figure 1).

The barrier reef consists of intertidal reef flats 1.5-4 km wide and up to 15 km long, aligned parallel to the mainland coast, enclosing a shallow shelf or lagoon with depths generally less than 10 m. Sand cays, the subject of this paper, are located on the reef flats. We here describe the easternmost islands (Fig.2) of Musal Tivu or Hare Island; Manauli; a small islet west of Manauli; New Island; and, more briefly, Krusadai Island or Kurisadi Tivu and Shingle Island. Other islands extending westward to Tuticorin were not visited.

There has been little previous work on these islands or their terrestrial biota. R.B. Foote (1883, 1888, 1890) described the adjacent coast and coral reefs, as did J. Walther (1891) and R.B. Seymour Sewell (1932; 1936, 474-477). Only Walther (1891, 18-21) spent any time on the cays, visiting Krusadai and Shingle Islands. Early work by E. Thurston (1887) on the marine fauna of the islands was extended following the establishment of a small marine station on Krusadai by the Government of Madras (Gravely et al. 1927) and of the Central Marine Fisheries Research Institute at Mandapam Camp by the Government of India. Detailed studies have appeared on the sponges (Burton 1937), Foraminifera (Daniel 1949a, 1949b), and corals (Pillai 1967) of the area. Since Gravely's work on the land fauna and flora, only outline guides have appeared on the land biota (Chacko et al. 1955). Stoddart and Pillai (1972) have described recently raised reefs on the mainland coast near Mandapam and Pamban and have considered their geological implications.

ENVIRONMENT

The environment of the Mannar barrier reef is dominated by the seasonal monsoonal wind reversal. Winds show a considerable annual variation (Fig. 3), from the north and northeast from November to February, and from the south in May to October. Mean wind speed is 6-11 knots (3-5.6 m/sec). The area with which we are concerned differs from most of mainland India in that, because of the rainshadow effect of the south Indian mountains, the summer (southwest) monsoon is dry and the winter (northeast) monsoon wet. Mean annual rainfall at Pamban, averaged over 62 years (1891-1936, 1938-1950, 1952-1954, in *Rainfall of India* (1891-1914) and *Monthly Rainfall of India* (1916-1954)) is 915 mm, of which 688 mm falls in October-December. Extreme annual totals were 353 mm in 1945 and 1772 mm in 1896. There is a

(Manuscript received Oct. 1971--Eds.)

considerable probability of no rain at all falling in all months except October-January, and rainfall totals during the summer months of July-August are extermely low (Fig. 4). Table 1 gives some indicators of rainfall variability.

Table 1. Rainfall data for Pamban

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean monthly rainfall in mm	64.3	20.2	19.8	47.0	24.0	4.0	11.0	12.9	25.4	208.1	289.1	190.3	915.3
Number of years during the period of record with less than 2.5 mm reported in the month	2	29	26	10	21	43	31	34	20	1	0	0	
Number of years with less than 2.5 mm in the month as percentage of total length of record	3.2	46.8	41.9	16.1	33.9	69.4	50.0	54.8	32.3	1.6	0	0	
Highest monthly total mm	282.7	120.4	126.7	267.0	217.2	70.1	174.0	103.6	133.1	548.1	692.2	839.7	
Lowest monthly total mm	0	0	0	0	0	0	0	0	0	0	32.8	6.1	

Period of record: 62 years (1891-1936, 1938-1950, 1952-1954).
Source of data: *Rainfall of India* (1891-1914), *Monthly Rainfall of India* (1916-1954).

Temperatures are high, with a mean daily maximum over the year of 31.1°C and minimum of 25.6°C (the highest and lowest monthly means being in May, 34.4°C, and December, 22.8°C, respectively). The absolute maximum temperature recorded at Pamban over 30 years is 37.2°C and the absolute minimum 18.9°C (Meteorological Office 1958, 34; Hydrographic Department 1961, 46).

A striking result of these general high temperatures, low and often unreliable rainfall, and constant wind is the appearance of aridity in the vegetation; Spate (1954, 731) refers to the "Red Sea aspect" of the Gulf of Mannar coastlands by contrast with the green littoral of Ceylon. The impression of aridity is reinforced by the presence of high dunes, part fixed (terai) and part mobile, built by southerly winds on south-facing coasts. These dunes are unimportant on northern shores, partly because of the shorter duration of the northeast monsoon but also because it coincides with heavier rainfall. High mobile dunes are found well inland west of Rameswaram on Rameswaram Island, and again west of Mandapam, and have to be cleared from houses, railways and roads. The vegetation is also much affected by the pressure of dense human and animal populations.

Tropical cylones occasionally occur, and because of the configuration of the coast may be accompanied by high storm surges. A major storm with high surge and much loss of life occurred in the Pamban-Rameswaram area in December 1964 (Bhaskara Rao and Mazumdar 1966a, 1966b).

Tides are mixed, mainly semidiurnal, becoming rather irregular and briefly diurnal at neaps. *Indian Tide Tables* predict a maximum range at springs of 0.81 m and at neaps of 0.2 m, but wind conditions influence tidal behaviour considerably in the Gulf of Mannar and Palk Bay area.

GENERAL CHARACTERISTICS OF THE CAYS

Several general observations may be made about the south Indian cays. With the exception of Shingle Island, standing on a small reef patch, they are sand structures with gravel forming a minor component and boulders rare. Though some, such as Musal Tivu, are large, they occupy a very small proportion of the reef-flats on which they stand. Except for the fact that they are located closer to the leeward (northern) than windward (southern) sides of the reefs, their location on the flats appears largely random; they are not associated, as are most sand cays, with gaps or prominent angles on the reef. The islands themselves have very irregular outlines, with spits and partially enclosed bays, and often higher sandy beach ridges enclose areas of mud flats and standing water within the cay. Crescentic, often unvegetated, sand bars are common offshore on the south sides of the islands.

These features suggest a sediment supply insufficient for major land accumulation on such exceptionally wide reef flats (up to 4 km wide compared with a more usual reef-flat width elsewhere of 1 km), even in conditions of low tidal range. Since cyclones do occur, it is remarkable that boulders and coarse debris are not more significant as island-anchors near the seaward reef edges. Mainly sand-size sediments are thus transported across exceptionally wide flats by waves which are unable to carry them to the leeward edges of the reefs, but the deposited sediments are inadequate in quantity, when deposited, to form more than irregular scattered sand bars and islands.

Except where sand dunes have been built on Musal Tivu, the islands are all extremely low, probably all less than 3 m above the level of high water springs. No beachrock or other cemented sediments outcrop on the islands. This is surprising in view of the raised reefs and cemented current-bedded sediments prominently outcropping on the adjacent mainland Indian coast, indicating local uplift at about 4,000 years B.P. (Stoddart and Pillai 1972): how the Mannar barrier relates to these features is not clear, but there is no evidence to suggest that the cays are other than recent formations. Beachrock is found on neighbouring Ceylon shores (Cooray 1968) and its absence on the Mannar cays has no obvious explanation.

DESCRIPTION OF THE CAYS

Musal Tivu or Hare Island (Fig. 5)

Musal Tivu is the largest island on the barrier reef, with a length of about 4 km, width ranging from 250 to 1800 m, and a total area of about 160 ha. It differs considerably from the other cays in its vegetation, probably because of the amount of human interference and the numbers of cattle, goats and donkeys kept there. In general aspect, with such species as *Borassus, Acacia, Calotropis* and *Cissus,* it closely resembles the adjacent Indian mainland.

The narrow central part of the cay is covered with a dense coconut woodland, with trees 20-25 years old in rows, cleared beneath, and with rows of *Borassus* palms, clearly planted, on both seaward and lagoonward sides. The lagoon shore is sandy and clearly prograding, 1.5-2 m high, with a pioneer vegetation of sedges and grasses *(Fimbristylis, Dactyloctenium)* and an interrupted line of shrubby trees slightly inland from the beach crest. These are mainly trees of *Thespesia populnea* up to 5 m tall, with some *Acacia; Scaevola taccada* is notably rare in what appears to be a very suitable habitat, and only a single shrub of this species was seen on the lagoon shore.

Towards the east on the lagoon shore the littoral hedge becomes more continuous, with *Acacia* and *Thespesia* dominant, while towards the end of the island the prograding beach is replaced by spits of sand and fine gravel, covered with *Pemphis acidula,* with beds of marine phanerogams offshore and enclosing wide flat meadows of grazed *Salicornia* and *Arthrocnemum* within. Grasses and sedges colonise slightly higher ground, and a few clumps of *Avicennia* grow in some channel openings. The vegetation of the cay interior is very open, with scattered trees of *Acacia* and *Thespesia* and herds of goats and cattle.

Most of the south coast has a wide beach about 3 m high from low-water level, with incipient sand dunes colonised by *Spinifex* and *Cissus,* with *Thespesia* and *Acacia* further inland. *Scaevola* and *Tournefortia* are both absent.

The western end of the island is wider, with an open woodland of *Acacia* and *Calotropis,* with *Cassia,* and lower areas are covered with a *Salicornia* sward. Open pools are surrounded by sparse *Avicennia* and open *Pemphis* woodland.

Apart from the *Pemphis* and *Thespesia* woodland, and the *Spinifex* and *Salicornia* areas, the vegetation of Musal Tivu differs considerably from that of the other islands. Mangroves are also poorly represented, though there is some evidence of cutting.

West Island (Manauli) (Fig. 6)

West Island is a small recent island west of Manauli; it is 740 m long, 150-190 m wide, and has an area of 10.7 ha. It consists of sand and fine gravel rising 1.5 to 2 m above low water level. The vegetation consists of herbs, vines and grasses, with some scattered trees and shrubs of *Thespesia* and *Pemphis,* and a belt of *Avicennia* and *Lumnitzera* mangrove woodland at the eastern end. Apart from a small area in the centre dominated by *Sporobolus virginicus,* the ground cover is a mixture of grasses *(Dactyloctenium, Apluda),* sedges *(Bulbostylis, Cyperus, Fimbristylis), Dolichos lablab,* and *Ipomoea pes-caprae.* Climbing *Ipomoea macrantha* covers the trees. *Launaea, Spinifex* and *Sesuvium* are common on the south shore, *Suaeda* on the north.

Manauli (Fig. 7)

Manauli is a cay of rather complex topography, 1 km long, 350 m wide, and with an area of 24 ha. The northern and southern beach ridges are separated by an area of *Thespesia* woodland up to 6 m tall, and lower scrub of *Pemphis acidula,* with pools and open mud flats. The south coast vegetation, on a flat, irregular, prograding beach, is dominated by *Spinifex, Sesuvium* and *Suaeda,* with *Atriplex* on the north shore, all forming rather discrete assemblages. There are scattered mangrove trees *(Lumnitzera, Rhizophora, Bruguiera, Ceriops),* especially along the north shore, but only *Avicennia* forms a closed woodland round the mudflats. In addition to *Thespesia* there are trees of *Cordia subcordata* and *Clerodendrum inerme* shrubs. Tall trees approach close to the sea on the north coast, where a slightly retreating beach faces a reef flat about 9.5 km wide, whereas on the south coast, facing a reef flat 2 km wide, there is a wide zone of pioneer grasses and herbs on the beach crest, and isolated patches of similar vegetation on low sand banks seaward of the main beach. Protected mudflats are colonised by swards of *Salicornia* and *Arthrocnemum.*

New Island (Fig. 8)

New Island, east of Manauli, has a similarly complex topography with interior open mud flats; it is 1100 m long, 120-500 m wide, and 30 ha in area. There is a wide *Avicennia* woodland on the north side, but other mangroves are less common (*Rhizophora, Lumnitzera* and *Ceriops* are also present). Much of the interior is covered either with *Thespesia* woodland with shrubs such as *Clerodendrum,* or with a high grassland of *Sporobolus,* with other grasses, such as *Dactyloctenium,* and sedges. Colonizers on the south shore include *Spinifex, Sesuvium, Ipomoea,* and *Suaeda,* with a fairly continuous hedge of *Pemphis* on the beach crest.

Kurisadi Tivu or *Krusadai Island*

Krusadai was visited but not mapped: a sketch map made in July 1924 is given by Gravely et al. (1927) but is on a very small scale. Seaward beach ridges have a diverse vegetation of grasses (*Dactyloctenium*), sedges (*Fimbristylis*), *Euphorbia* species, *Dolichos lablab,* and *Ipomoea pes-caprae,* with *Thespesia* woodland inland. Mangrove woodland is extensively developed on the north coast. Many ornamental species have been planted round the scientific station. A list of plants from Krusadai was given by Parthasarathy Iyengar (1927).

Shingle Island

A landing was made on Shingle Island but no collections were made. It has higher steeper beaches, or coral gravel, than the other islands. According to a sketch map in Gravely et al. (1927) it consisted of two separate islands in 1878, and these coalesced to form the present single island by 1920-27.

MAIN FEATURES OF THE VEGETATION

The vegetation of these south Indian sand cays differs so considerably from that of western and central Indian Ocean reef islands that it is useful to review its main characteristics for comparative purposes.

Marine grass meadows

Marine grass meadows are extensive on the reef flats, in this resembling Indian Ocean continental coasts and the reefs of the southwest Indian Ocean (e.g. Aldabra) rather than the more isolated reefs of the open ocean (e.g. Chagos). The flora includes two species of *Cymodocea,* one of *Halodule,* one of *Syringodium,* one of *Thalassodendron,* one of *Enhalus,* two of *Halophila,* and one of *Thalassia.*

Mangrove woodland

Mangrove woodland is less extensive on the cays than might be expected from the presence of *Bruguiera, Ceriops, Rhizophora, Lumnitzera* and *Avicennia;* it is absent from the adjacent mainland coasts, where it is replaced by tropical salt-marsh vegetation. On the cays *Avicennia* is the most common mangrove, forming a woodland less than 5 m tall. Other genera are often represented only by scattered trees on protected shores.

Salt-marsh vegetation

Extensive mud-flat areas enclosed by sand spits are covered with meadows of *Arthrocnemum* and *Salicornia,* genera apparently absent from central Indian Ocean atolls. The meadows are often surrounded on slightly high ground by banks of *Suaeda maritima,* as in temperate salt-marshes, with *Sesuvium, Bulbostylis,* and *Fimbristylis* on flat but drier ground.

Beach vegetation

Pioneer and beach crest vegetation on the cays is variable. Common pioneers are *Sporobolus virginicus* and *Cyperus conglomeratus* on advancing coasts. In established vegetation, *Spinifex squarrosus* and *Sesuvium portulacastrum* seem to be more common on windward (southern) shores, and *Atriplex repens* on leeward shores. Beach-crest shrub vegetation is dominated either by *Thespesia populnea,* where interior woodland reaches the beach, or by the very common *Pemphis acidula.* The unimportance of common reef-island species in this community is remarkable: *Tournefortia argentea* and *Sophora tomentosa* have not been recorded, *Suriana maritima* though recorded in 1927 was not seen during the present survey, and *Scaevola taccada* is very uncommon except on Shingle Island. *Pemphis,* which grows to a height of 6 m., is more common on leeward shores, and on retreating beaches. Incipient dunes, common only on Musal Tivu, are covered with *Spinifex* and *Acacia,* as on the adjacent mainland.

Interior woodland

It seems likely that the ultimate vegetation of these cays is a woodland of *Thespesia populnea,* with trees up to 6 m tall. Few other trees are recorded *(Cordia, Premna, Salvadora, Calotropis)* and some are probably introduced. *Acacia* is common only on Musal Tivu, subject to much greater human disturbance than the other islands, and both coconuts and Palmyra palms are important only on this island. Again the absence of common atoll trees in the interior woodland is very noticeable (e.g. *Hernandia, Calophyllum).*

Interior mixed grass and herb vegetation

Woodland covers only a small proportion of the cay surface, the rest being covered with low shrubs, herbs, vines and grasses. *Dactyloctenium, Sporobolus, Trachys* and *Apluda* are the most common grasses. *Ipomoea macrantha* is widespread on shrubs and low trees, while *Ipomoea pes-caprae* is more common on the ground. *Dolichos lablab* is particularly abundant.

LIST OF VASCULAR PLANTS

Plants of Krusadai Island were listed by Parthasarathy Iyengar (1927), who found 31 species. Some additional records of marine phanerogams are given by Den Hartog (1970). Species listed by both are included in the following list of plants collected in December 1968 and January 1969 and determined by F.R. Fosberg. The area lies within that covered by Gamble's (1915-36) Flora of Madras, though no island localities are given in that work. 84 species are now recorded from the cays (Musal Tivu or Hare, 34; Manauli, 54; West Island, 24; New Island, 25; Krusadai, 42).

PANDANACEAE

Pandanus odoratissimus Forsk.
Krusadai: listed by Parthasarathy Iyengar (1927).

POTAMOGETONACEAE

Cymodocea rotundata Ehrenb. and Hempr. ex Aschers.
Manauli: *Fosberg 51281.*
Krusadai: listed by Parthasarathy Iyengar (1927); collected in 1944 by Parthasarathy Iyengar and D. Daniel, in Den Hartog (1970).

Cymodocea serrulata (R. Br.) Aschers. and Magnus.
Musal Tivu (Hare): collected in 1928 by F. Børgensen, in Den Hartog (1970).
Krusadai: listed by Parthasarathy Iyengar (1927); collected, no date, by J. Gopelstao, in Den Hartog (1970); *Fosberg 51234*.

Halodule sp.
Manauli: *Fosberg 51280*.

Syringodium isoetifolium (Aschers.) Dandy
Musal Tivu (Hare): collected in 1928 by F. Børgesen, in Den Hartog (1970).
Krusadai: listed as *Cymodocea isoetifolia* by Parthasarathy Iyengar (1927).

Thalassodendron ciliatum (Forsk.) d. Hart. [*Cymodocea ciliata* (Forsk.) Koen.]
Manauli: *Fosberg 51282*.

HYDROCHARITACEAE

Enhalus acoroides (L. f.) Royle
Krusadai: listed as *Enhalus koenigii* by M.O. Parthasarathy Iyengar (1927); collected in 1944 by S.V. Parthasarathy and D. Daniel, in Den Hartog (1970).

Halophila ovalis (R. Br.) Hook. f.
Musal Tivu (Hare): collected in 1928 by F. Børgesen, in Den Hartog (1970).
Krusadai: listed by Parthasarathy Iyengar (1927); collected in 1928 by M.O. Parthasarathy Iyengar, in Den Hartog (1970).

Halophila stipulacea (Forsk.) Aschers.
Krusadai: listed by Parthasarathy Iyengar (1927); *Fosberg 51233*.

Thalassia hemprichii (Ehrenb.) Aschers.
Manauli: *Fosberg 51279*.

GRAMINEAE

Apluda mutica L.
West Island: *Stoddart 1519*.
Manauli: *Stoddart 1544, 1548; Fosberg 51270* (det. T.R. Soderstrom).
New Island: *Stoddart 1604*.

Dactyloctenium aegyptium (L.) Beauv. *s.l.*
West Island: *Stoddart 1504*.
Musal Tivu (Hare): *Stoddart 1563*.
Manauli: *Stoddart 1541; Fosberg 51267*.
New Island: *Stoddart 1605* (or undescribed species), *1606*.
Krusadai: *Fosberg 51222* (somewhat like *D. sindicum)*.

Eragrostis tenella (L.) Beauv.
Musal Tivu (Hare): *Stoddart 1582*.

Eragrostis tenella var. *insularis* Hubb.
Musal Tivu (Hare): *Stoddart 1579*.
Manauli: *Fosberg 51251*.

Haplopyrum mucronatum (L.) Stapf
West Island: *Stoddart 1510.*
Manauli: *Fosberg 51254.*

Spinifex littoreus (Burm. f.) Merr.
Musal Tivu (Hare): *Stoddart 1575.*
West Island: *Stoddart 1524.*
Manauli: *Stoddart 1528.*
New Island: *Stoddart 1594.*
Krusadai: listed as *Spinifex squarrosus* by Parthasarathy Iyengar (1927).

Sporobolus sp.
West Island: *Stoddart 1517.*

Sporobolus fertilis (Steud.) Clayt.
New Island: *Stoddart 1601.*

Sporobolus maderaspatanus Bor
Manauli: *Stoddart 1542; Fosberg 51252.*

Sporobolus marginatus Hochst. ex Rich.?
Manauli: *Fosberg 51263.*

Sporobolus tremulus (Willd.) Kunth
Manauli: *Fosberg 51271.*

Sporobolus virginicus (L.) Kunth
West Island: *Stoddart 1522.*
Manauli: *Stoddart 1543; Fosberg 51250.*
New Island: *Stoddart 1596.*

Trachys muricata (L.) Pers.
Musal Tivu (Hare): *Stoddart 1566.*
Manauli: *Stoddart 1532; Fosberg 51253.*
Krusadai: *Fosberg 51223.*

CYPERACEAE

Bulbostylis barbata Kunth
Musal Tivu (Hare): *Stoddart 1569, 1589.*
West Island: *Stoddart 1514.*
Manauli: *Fosberg 51255, 51269.*
New Island: *Stoddart 1602.*

Cyperus arenarius Retz.
Krusadai: listed by Parthasarathy Iyengar (1927).

Cyperus aristatus Rottb.
Manauli: *Fosberg 51276, 51277.*

Cyperus bulbosus Vahl
Manauli: *Stoddart 1538; Fosberg 51256.*
New Island: *Stoddart 1603.*

Cyperus conglomeratus Rottb.
West Island: *Stoddart 1503.*
Manauli: *Stoddart 1527; Fosberg 51265.*
New Island: *Stoddart 1592.*
Krusadai: possibly listed as *Cyperus* "big species" by Parthasarathy Iyengar (1927).

Cyperus cuspidatus H.B.K.?
Manauli: *Fosberg 51278.*

Fimbristylis cymosa R. Br.
Musal Tivu (Hare): *Stoddart 1568, 1586.*
West Island: *Stoddart 1507.*
Manauli: (?) *Stoddart 1540; Fosberg 51273.*
New Island: *Stoddart 1590.*
Krusadai: *Fosberg 51224.*

Fimbristylis polytrichoides R. Br. ?
Musal Tivu (Hare): *Stoddart 1580.*
Manauli: *Stoddart 1539.*

PALMAE

Borassus flabellifer L.
Musal Tivu (Hare): seen by Stoddart, January 1969.

Cocos nucifera L.
Musal Tivu (Hare): seen by Stoddart, Jan. 1969.
Krusadai: seen by Stoddart, Jan. 1969.

LILIACEAE

Iphigenia sp. [cf. *I. indica* A. Gray or *I. pallida* Bak.]
Krusadai: *Fosberg 51230.*

CHENOPODIACEAE

Arthrocnemum sp.
Manauli: *Fosberg 51244.*

Arthrocnemum indicum (Willd.) Moq.
Krusadai: listed by Parthasarathy Iyengar (1927).

Arthrocnemum fruticosum var. *glaucum* Moq.
Krusadai: listed by Parthasarathy Iyengar (1927).

Atriplex repens Roth
Manauli: *Stoddart 1536, 1549; Fosberg 51241.*
New Island: *Stoddart 1600.*
Krusadai: listed by Parthasarathy Iyengar (1927).

Salicornia sp.
Musal Tivu (Hare): *Stoddart 1585* (seedling).
Manauli: *Stoddart 1547* (seedling).

Salicornia brachiata Roxb.
Manauli: *Fosberg 51243, 51245.*

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Suaeda maritima Dum.
West Island: *Stoddart 1520.*
Manauli: *Stoddart 1537; Fosberg 51264.*
New Island: *Stoddart 1591.*
Krusadai: listed by Parthasarathy Iyengar (1927).

Suaeda monoica Forsk.
Manauli: *Fosberg 51272.*
Krusadai: listed by Parthasarathy Iyengar (1927).

AMARANTHACEAE

Aerva tomentosa Forsk.
Musal Tivu (Hare): *Stoddart 1564.*
Manauli: *Stoddart 1533; Fosberg 51257.*
Krusadai: *Fosberg 51228.*

AIZOACEAE

Sesuvium portulacastrum (L.) L.
West Island: *Stoddart 1506.*
Manauli: *Stoddart 1531; Fosberg 51266.*
New Island: *Stoddart 1607.*
Krusadai: listed by Parthasarathy Iyengar (1927), also listed as var. *repens.*

LAURACEAE

Cassytha filiformis L.
Krusadai: listed by Parthasarathy Iyengar (1927).

LEGUMINOSAE

Acacia sp.
Musal Tivu (Hare): seen by Stoddart, Jan. 1969.

Caesalpinia sp.
West Island: *Stoddart 1511.*

Caesalpinia bonducella (L.) Flem.
Krusadai: listed by Parthasarathy Iyengar (1927) [= *C. bonduc.* (L.) Roxb. ?].

Cassia acutifolia Del.
Musal Tivu (Hare): *Stoddart 1559.*

Dolichos lablab L.
West Island: *Stoddart 1512.*
Manauli: *Stoddart 1545; Fosberg 51246.*
New Island: *Stoddart 1597.*

Indigofera oblongifolia Forsk.
Musal Tivu (Hare): *Stoddart 1561.*
Krusadai: *Fosberg 51226.*

SURIANACEAE

Suriana maritima L.
Krusadai: listed by Parthasarathy Iyengar (1927).

EUPHORBIACEAE

Euphorbia indica Lam.
West island: *Stoddart 1523.*
Manauli: *Fosberg 51260.*

Euphorbia microphylla Heyne?
Musal Tivu (Hare): *Stoddart 1562.*
Krusadai: *Fosberg 51231a* (glabrous form), *51231b.*

Excoecaria agallocha L.
Manauli: *Fosberg 51236.*
Krusadai: listed by Parthasarathy Iyengar (1927).

Phyllanthus maderaspatensis L.
Manauli: *Fosberg 51268.*

SALVADORACEAE

Salvadora persica L.
New Island: *Stoddart 1593.*

SAPINDACEAE

Dodonaea viscosa L.
Krusadai: *Fosberg 51229.*

RHAMNACEAE

Zizyphus mauritiana Lam.
Musal Tivu (Hare): *Stoddart 1578.*

VITACEAE

Cissus quadrangularis L.
Musal Tivu (Hare): *Stoddart 1584.*

MALVACEAE

Thespesia populnea (L.) Sol. ex Correa
Musal Tivu (Hare): *Stoddart 1565.*
West Island: *Stoddart 1518.*
Manauli: *Stoddart 1526.*
Krusadai: listed by Parthasarathy Iyengar (1927); *Fosberg 51232, 51235.*

Thespesia populneoides (Roxb.) Kostel.?
New Island: *Stoddart 1598.*

LYTHRACEAE

Nesaea lanceolata Koehne
Manauli: *Fosberg 51275.*

Pemphis acidula Forst.
Musal Tivu (Hare): *Stoddart 1577.*
West Island: *Stoddart 1508.*
Manauli: *Stoddart 1535; Fosberg 51237.*
New Island: *Stoddart 1609.*
Krusadai: listed by Parthasarathy Iyengar (1927).

RHIZOPHORACEAE

Bruguiera cylindrica W. and A.
Manauli: *Stoddart 1555; Fosberg 51239.*
Krusadai: listed as *Bruguiera caryophylloides* by Parthasarathy Iyengar (1927).

Ceriops tagal (Perr.) C.B. Rob.
Manauli: *Stoddart 1554; Fosberg 51238.*
New Island: *Stoddart 1613, 1616.*
Krusadai: listed as *Ceriops candolleana* by Parthasarathy Iyengar (1927).

Rhizophora mucronata Lam.
Manauli: *Stoddart 1552; Fosberg 51248.*
New Island: *Stoddart 1611.*
Krusadai: listed by Parthasarathy Iyengar (1927).

COMBRETACEAE

Lumnitzera racemosa Willd.
West Island: *Stoddart 1516.*
Manauli: *Stoddart 1551; Fosberg 51240.*
New Island: *Stoddart 1612.*
Krusadai: listed by Parthasarathy Iyengar (1927).

GENTIANACEAE

Enicostema hyssopifolium (Willd.) Veldk.
West Island: *Stoddart 1513.*
Manauli: *Fosberg 51261.*
New Island: *Stoddart 1599.*

ASCLEPIADACEAE

Calotropis gigantea (Ait.) Ait.
Musal Tivu (Hare): *Stoddart 1560.*
Krusadai: listed by Parthasarathy Iyengar (1927).

CONVOLVULACEAE

Ipomoea macrantha R. and S. [*I. tuba* (Schlecht.) G. Don]
Musal Tivu (Hare): *Stoddart 1574.*
West Island: *Stoddart 1502.*
Manauli: *Stoddart 1530.*
New Island: *Stoddart 1595.*

Ipomoea pes-caprae (L.) R. Br. subsp. *pes-caprae*
Musal Tivu (Hare): seen by Stoddart, Jan. 1969.
West Island: *Stoddart 1505.*
Manauli: *Stoddart 1529.*
Krusadai: listed as *Ipomoea biloba* by Parthasarathy Iyengar (1927).

BORAGINACEAE

Cordia subcordata Lam.
Manauli: *Stoddart 1556.*

VERBENACEAE

Avicennia marina L.
West Island: (?) *Stoddart 1515.*
New Island: (?) *Stoddart 1614.*
Manauli: *Fosberg 51242.*
Krusadai: listed as *Avicennia officinalis* by Parthasarathy Iyengar (1927).

Clerodendrum inerme (L.) Gaertn.
Manauli: *Stoddart 1553; Fosberg 51247.*
New Island: *Stoddart 1615.*

Premna obtusifolia R. Br.
Musal Tivu (Hare): *Stoddart 1571.*

Premna wightiana Schauer?
Manauli: *Stoddart 1550.*

LABIATAE

Leucas stricta Benth.?
Musal Tivu (Hare): *Stoddart 1581.*

SOLANACEAE

Physalis angulata L.
Manauli: *Fosberg 51258.*

PEDALIACEAE

Pedalium murex L.
Musal Tivu (Hare): *Stoddart 1573.*

RUBIACEAE

Hedyotis sp. [*Oldenlandia umbellata* L., *non Hedyotis umbellata* Walt.]
Musal Tivu (Hare): *Stoddart 1587.*
Manauli: *Fosberg 51259.*

Hedyotis herbacea L.
Manauli: *Fosberg 51274.*

Spermacoce articularis L. f.
Musal Tivu (Hare): *Stoddart 1570.*

CUCURBITACEAE

Coccinea indica W. and G.
Musal Tivu (Hare): *Stoddart 1567.*

Cucumis melo var.
West Island: *Stoddart 1501.*
Manauli: *Stoddart 1534; Fosberg 51249.*
New Island: *Stoddart 1608.*

GOODENIACEAE

Scaevola taccada (Gaertn.) Roxb.
Musal Tivu (Hare): *Stoddart 1572.*
Krusadai: listed as *Scaevola lobelioides* by Parthasarathy Iyengar (1927).

COMPOSITAE

Blumea amplectens DC.
Krusadai: *Fosberg 51227.*

Eclipta alba (L.) Hassk.
Musal Tivu (Hare): *Stoddart 1583.*
Manauli: (?) *Stoddart 1558.*

Lactuca intybacea Jacq.
Manauli: *Fosberg 51262.*

Launaea sarmentosa Sch.-Bip. ex O. Ktze
Musal Tivu (Hare): *Stoddart 1588.*
West Island: *Stoddart 1520.*
Manauli: *Stoddart 1546.*
Krusadai: listed by Parthasarathy Iyengar (1927) as *Launaea pinnatifida.*

Vernonia cinerea (L.) Less.
Musal Tivu (Hare): *Stoddart 1576.*
West Island: *Stoddart 1509.*
New Island: *Stoddart 1610.*
Krusadai: *Fosberg 51225.*

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NOTE

The flora of Hare and Church Islands off Tuticorin, by D. Daniel Sundararaj and M. Nagarajan, J. Bombay Nat. Hist. Soc. 61: 587-602, 1964(1965), concerns another Hare Island, located well to the southwest of Adam's Bridge, opposite Tuticorin.

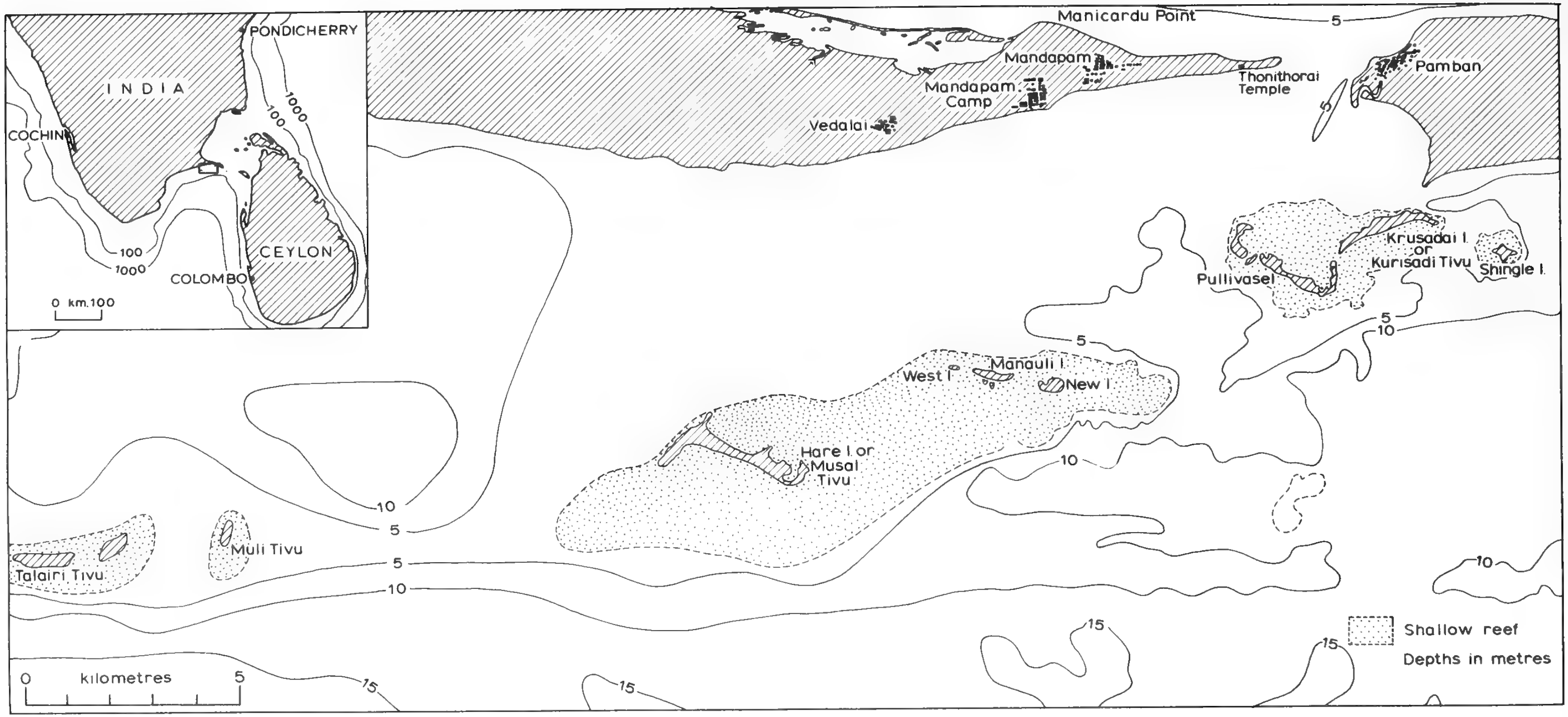

Figure 2. Reefs and sand cays south of Mandapam, Gulf of Mannar

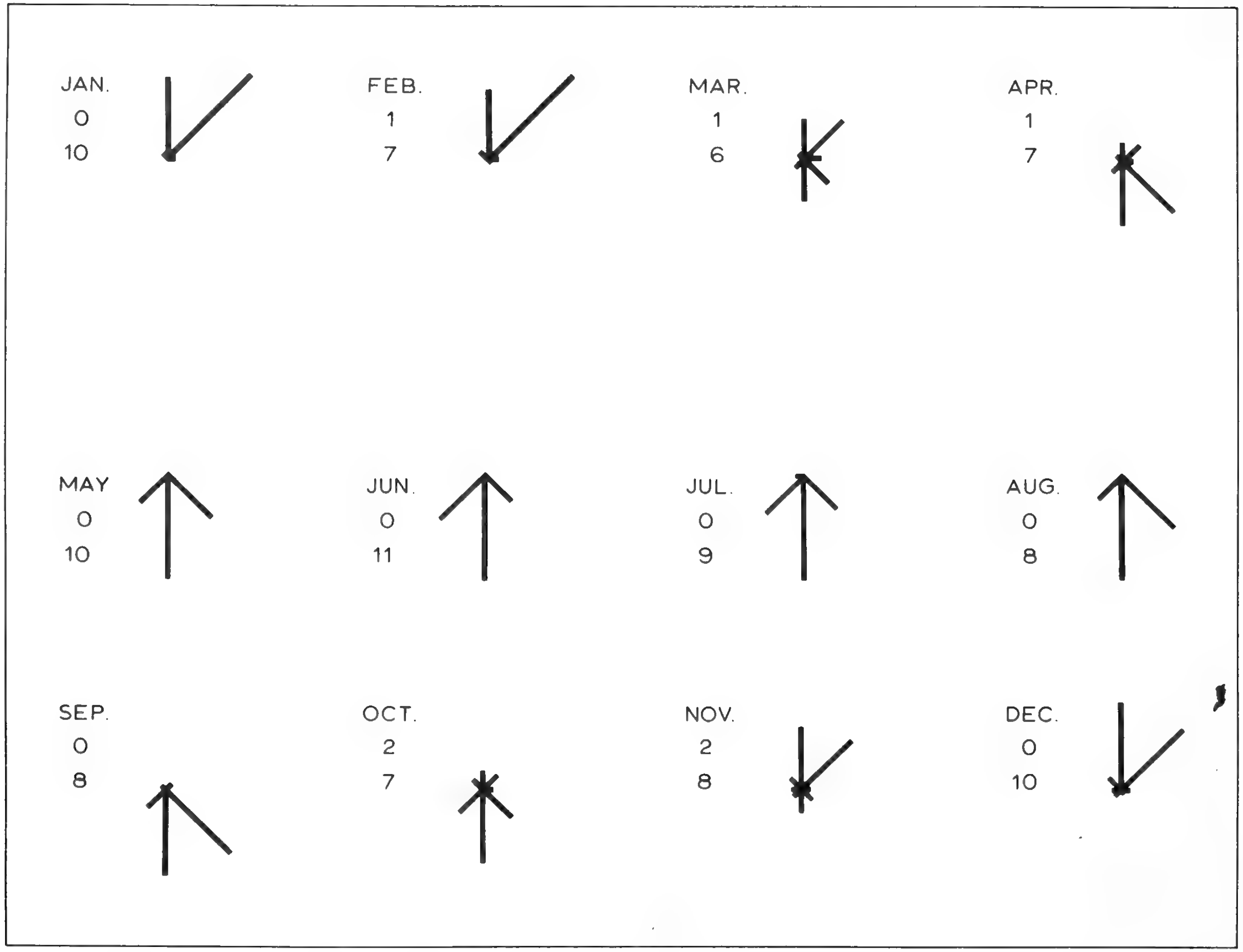

Figure 3. Monthly wind roses for Pamban (percentage of observations at 1730 hours, 5 year data). Upper figure shows percentage calms and lower figure mean wind speed in knots. Source of data: Hydrographic Department (1961, p. 46)

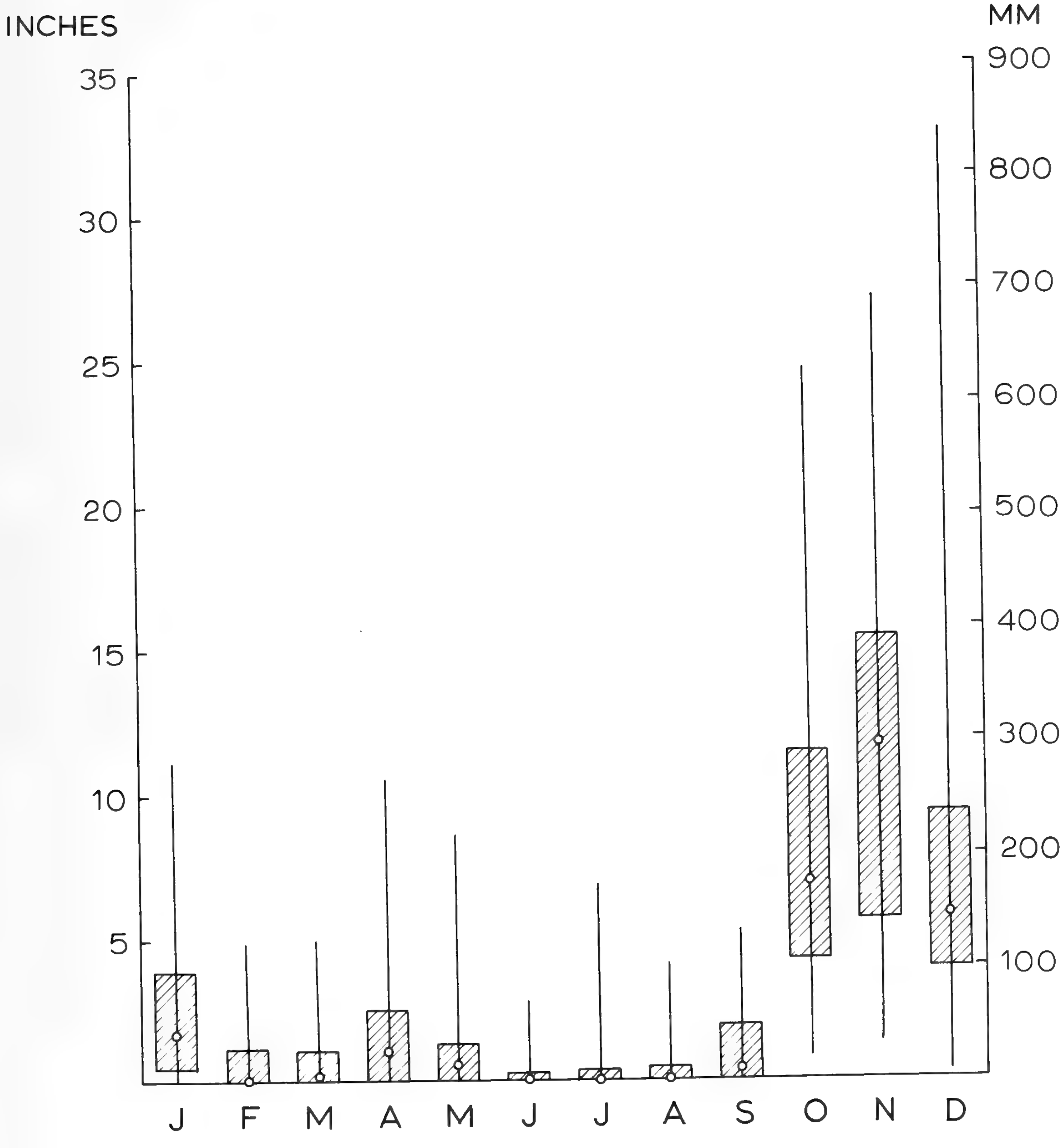

Figure 4. Mean monthly rainfall, monthly extremes, and monthly quartile ranges for 62 years of record at Pamban. Source of data: Meteorological Department, Government of India (1891-1954).

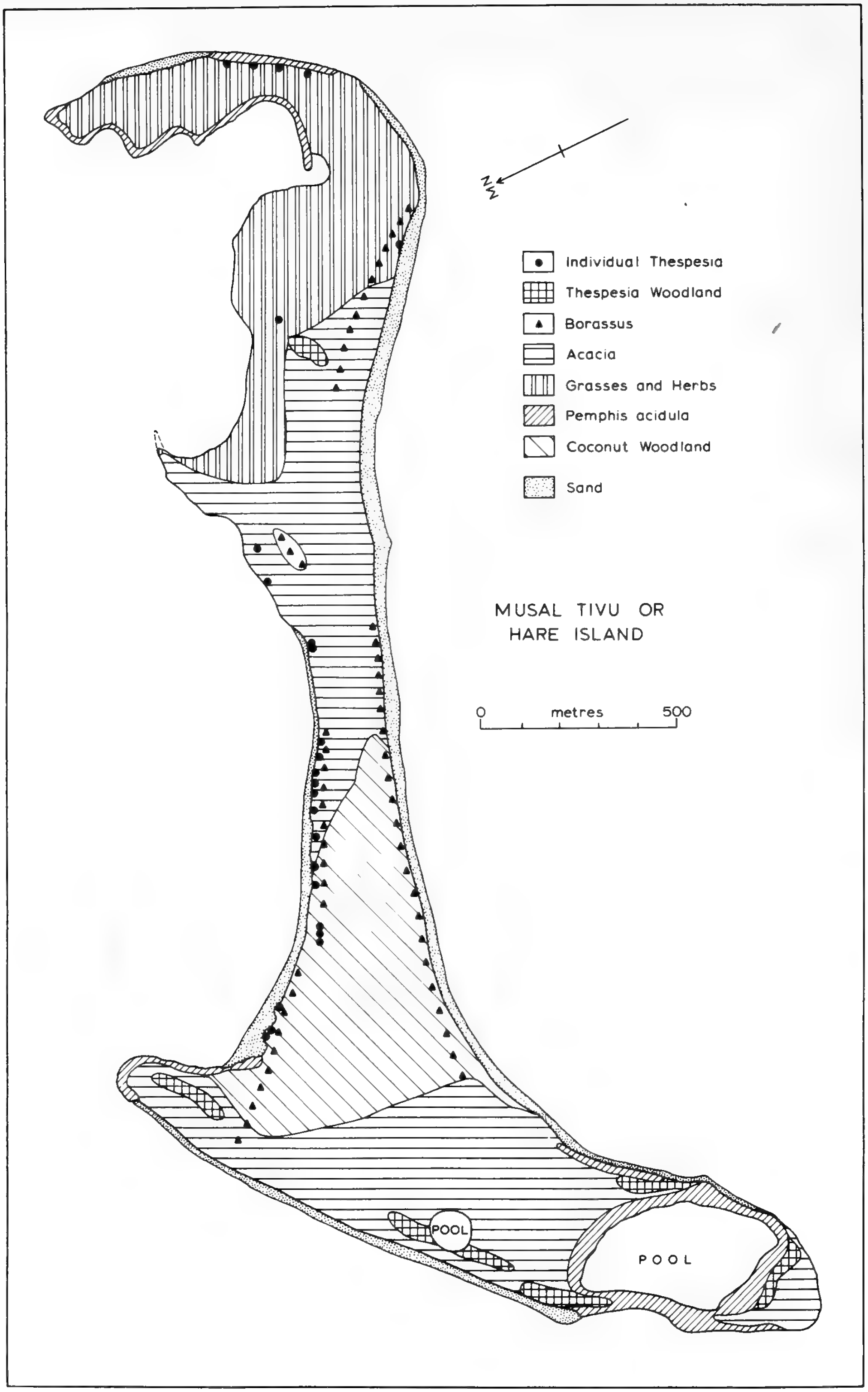

Figure 5. Musal Tivu or Hare Island. This and the following figures based on prismatic compass and pacing surveys

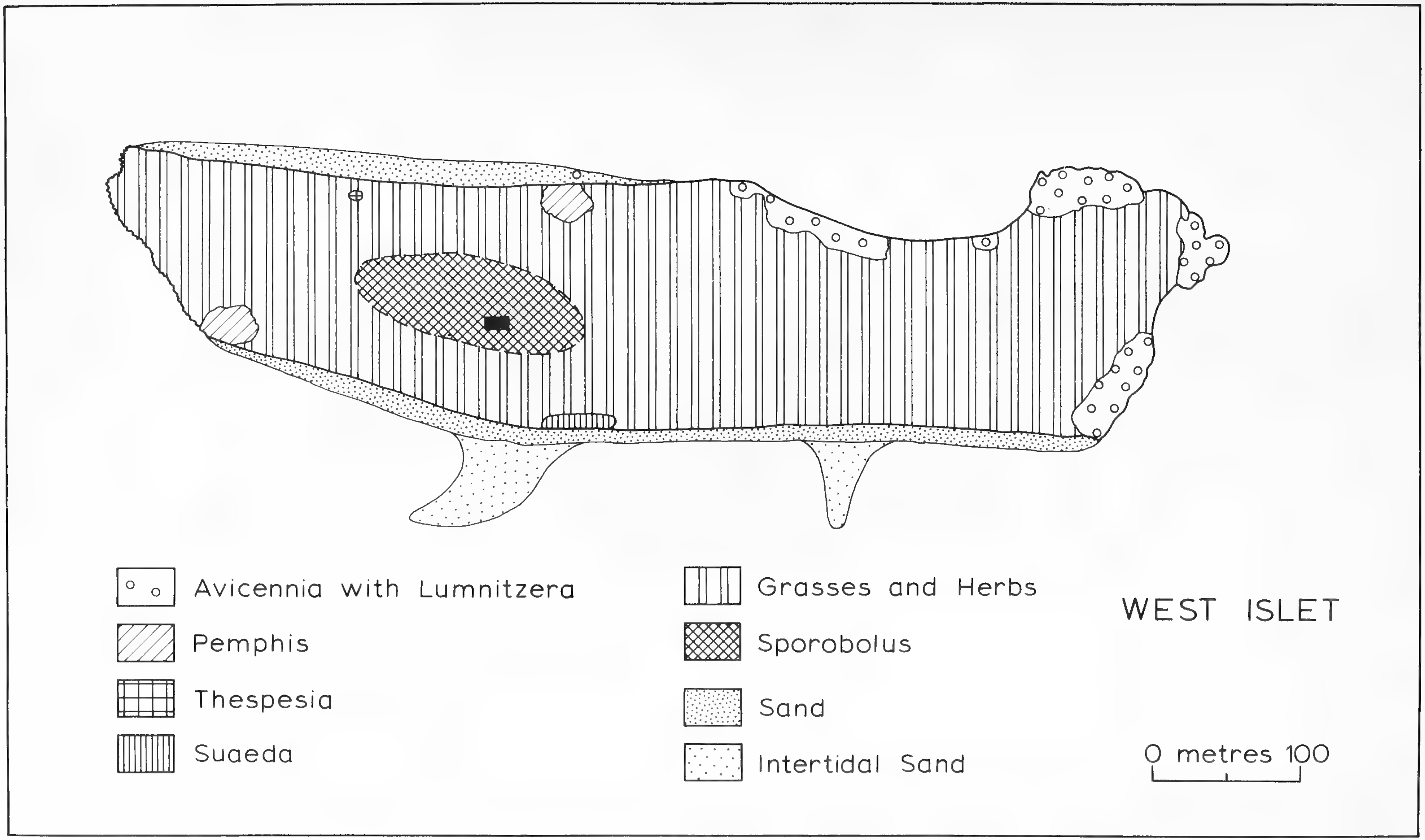

Figure 6. West Island

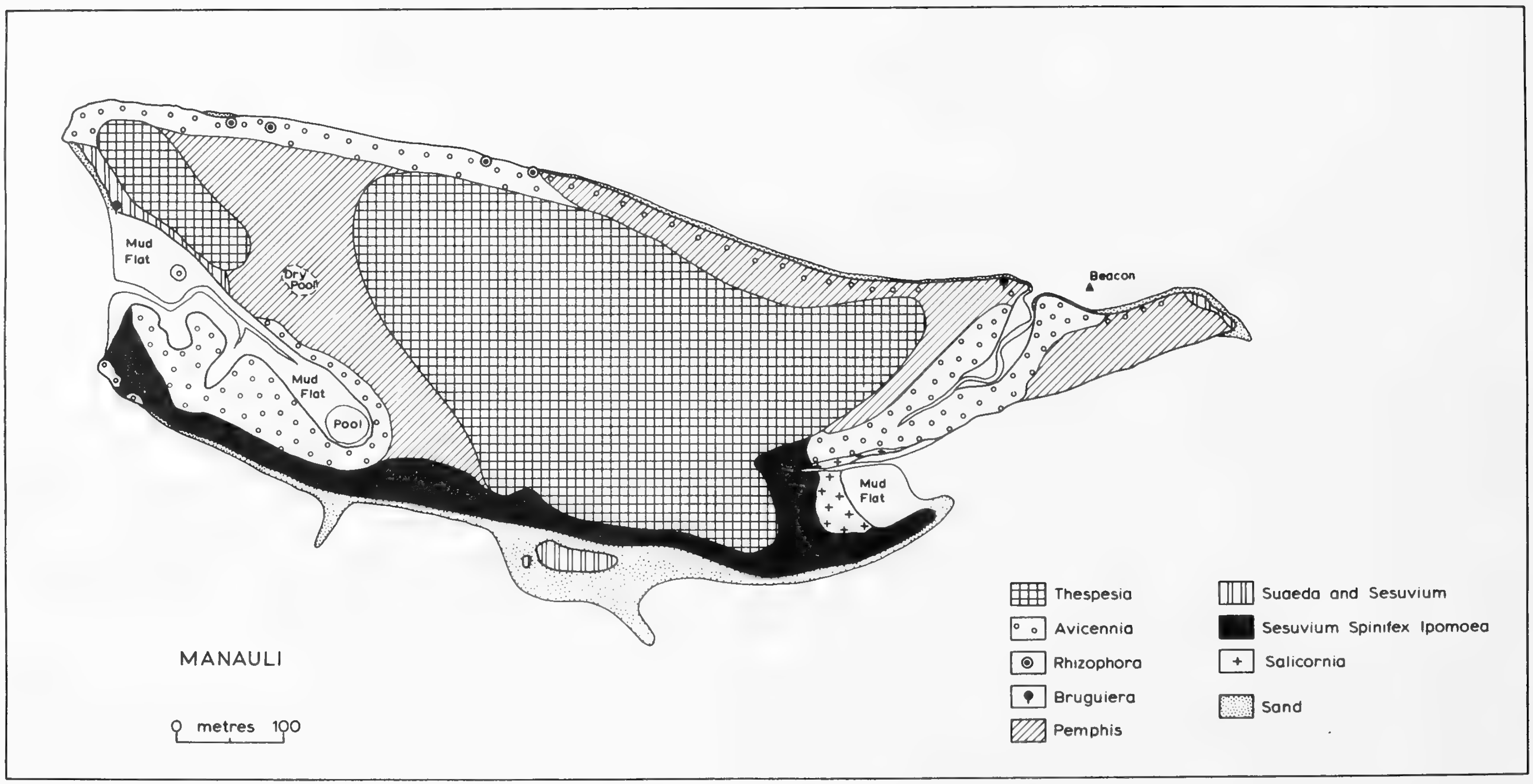

Figure 7. Manauli

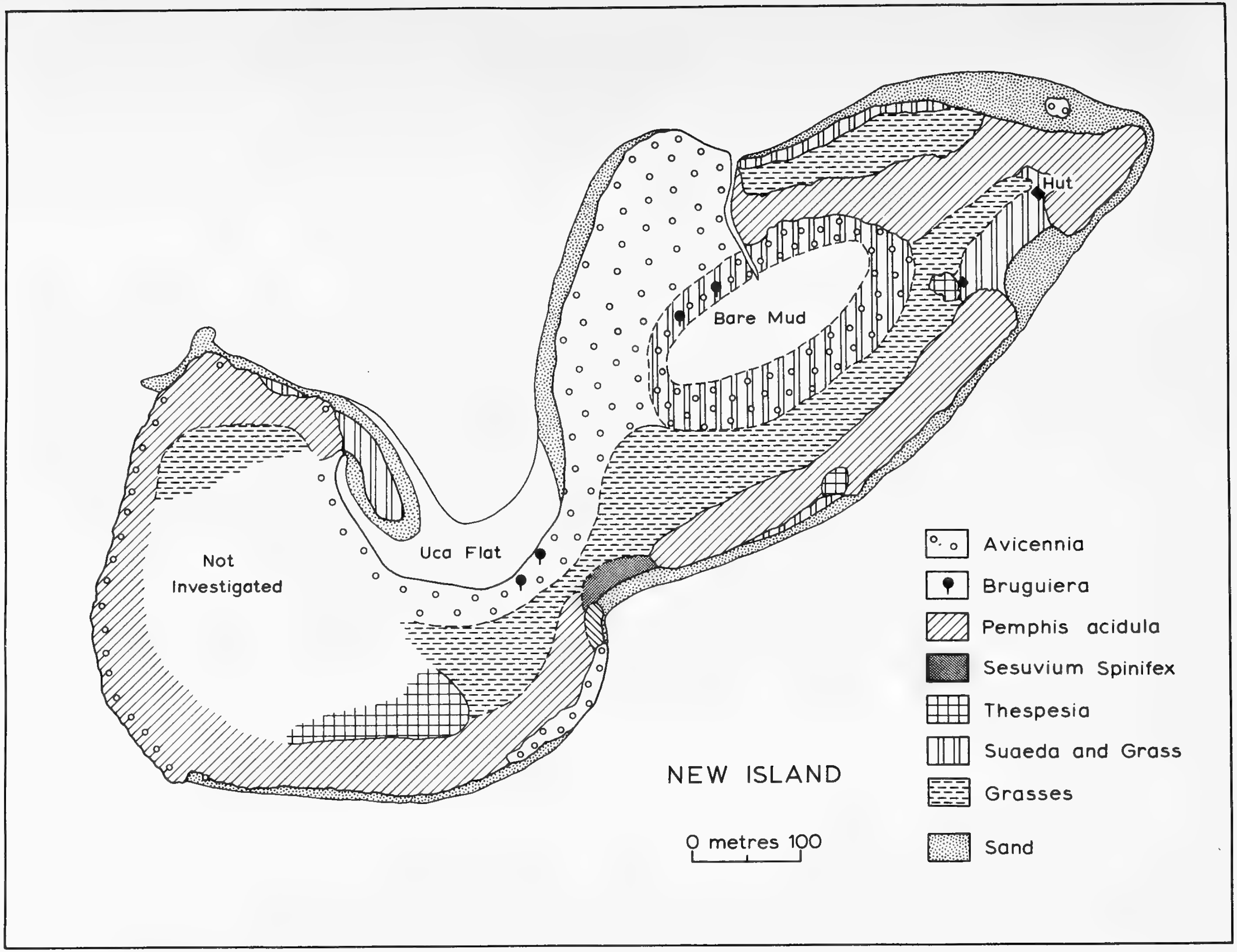

Figure 8. New Island

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ISLAND NEWS AND COMMENT

Readers will notice a neater format in this Bulletin. It is not a permanent improvement but is the result of very welcome, though temporary, help from the U.S. Air Force (AF/LGFC, Hq USAF). We owe the nice appearance of this issue to Mrs. Martha M. Green, of that Air Force unit, who did the final typing; our best thanks to her. This help bailed us out of a difficult situation for this issue. The next one will appear thanks to the Bureau of Sports Fisheries and Wildlife. After that we will probably be in trouble again. If any of our audience has any ideas on how we can get camera-ready copy typed on an "editing typewriter" or "word-processing machine," with no funds to pay for it, we would appreciate suggestions. We simply cannot handle the burden of repeated proof-reading of work done on an ordinary machine. We hope to get the production of the ARB back on a stable basis soon, but have had some bad breaks recently.

Since the last Island News and Comment appeared, the Island Bibliography Supplement, by Sachet and Fosberg, has been published (see under Publications). A leaflet has been sent to ARB readers to this effect. As there will be no further printed supplements to this volume, the section on Publications, Briefly Noted Items, will include lists of current publications on islands and reefs. Mrs. Linda Smith has volunteered to compile these lists for marine subjects and Dr Bryce G. Decker for terrestrial ones. Reprints and references sent to us will make this task easier and the lists more complete. We are always glad to receive good reviews of appropriate works within our scope, as well as news items, comments on pertinent subjects, and short original papers.

NEWS

PALAEOECOLOGY OR REEFS: The Palaeontological Association organized a one-day symposium at Edinburgh on 9 September 1971 as part of the joint meeting of British Geological Societies. Papers covered both modern and ancient reefs. In the former class, several of the papers were based on work either in the Seychelles or at Aldabra. Thus Dr E.Drew spoke on "Reef front phenomena of Aldabra: an ecological interpretation;" Dr J. Taylor on "Habitat complexity and faunal diversity on Recent reefs;" Mr. B.R. Rosen on "Ecological stratification in coralline environments;" and Dr. C.J.R. Braithwaite on "Ecology, palaeoecology and reef recognition." Two papers drew on recent work at Bermuda. Dr P. Garrett considered "Bermuda lagoon reefs and their palaeoecological significance," and was concerned with the ways that small coral colonies develop into micro-atolls and then into patch reefs or, as he termed them, mesa-reefs. He stressed the importance of biological erosion concurrent with growth, and showed that a large percentage of the volume of patch reefs was open cavity. Dr T.P. Scoffin also drew on West Atlantic experience in interpreting the "Conditions of growth of the Wenlock reefs of Shrophire." The fossil reefs covered a wide range: Palaeozoic (Dr C.T. Scrutton), Mesozoic (Dr F.M. Broadhurst and Dr I.M. Simpson on Derbyshire; Mr. J. Miller on west Yorkshire; Dr D.B. Smith on the Permian in Durham and in the Guadeloupe Mountains of Texas), and Coenozoic (Dr E.B. Wolfenden and Dr D.D. Bayliss on the Libyan Palaeocene). Dr G. Farrow also spoke on rudist reefs.

The often heated discussion revealed a sharp difference of view between the ecologists and the palaeoecologists. The latter were content with a catholic interpretation of the term reef; the former, impressed by the thinness of many modern reefs and the fact that coral communities are not necessarily reef structures nor are reef structures necessarily covered with coral communities, wanted a more precise definition which they were themselves, however, unable to succinctly provide. Brian Rosen summarized the position lucidly when he pointed out that modern reefs are growing in highly atypical immediately post-glacial conditions, and it is hence difficult to extend concepts of reef structure derived from the study of modern reefs to those in the past. Dr Braithwaite considered, however, that there were certain criteria of scale, zonation and structure (in the sense of frame-building) that must be satisfied before the term reef could legitimately be used. It was noticeable that some of the palaeoecologists used terms such as "reef flat," derived from contemporary reefs, without considering the extent to which these forms owed their characteristic features to the highly unusual conditions of the last several thousand years. The discussion ended rather inconclusively, with the palaeoecologists on the whole unconvinced that the issue of reef definition was a real one, and the ecologists unable to provide a convincing definition of what they considered to be a reef.

In summing up Sir Maurice Yonge drew attention to the need for further work on corals as animals. He noted recent work on the role of zooxanthellae in coral nutrition, on competition between corals, and on the testing of species in corals by immunological methods, and he stressed the need for long-term study of population fluctuations on reefs, possibly on islands set aside as laboratories by the Islands for Science Programme. One was left with the feeling that more palaeoecologists should follow the lead given by Newell twenty years ago and study modern reefs as well as ancient ones--but that comment comes from a modern reef-man, not an ancient one; the latter might well reverse it.

D. R. S.

Apropos of some of the remarks reported from this symposium it may be well to remind readers that regardless of the supposedly atypical conditions under which modern reefs are growing, reports on the cores and cuttings from the various deep drillings on atolls and barrier reef islands, some going back to the early Eocene or even late Cretaceous, do not indicate any startling difference or new characteristics introduced in the structures produced during the last few thousand years. A survey of fossil reefs made some years ago by Ted Ballard indicated that the great preponderance of reef growth throughout geological time has taken place during periods of transgression (personal communication). On a geological scale, at least, that is what post-glacial time has been.

F.R.F.

NEW INDIAN OCEAN RADIOCARBON DATES: D. P. Agrawal, S.K. Gupta and S. Kusumgar ("Tata Institute radiocarbon date list VIII") report some new dates from reef areas in the Indian Ocean in *Radiocarbon* 13: 84-93, 1971. Samples collected by S.G. Patil from Minicoy are dated as follows: TF-1017, coral, depth 3 m, 1575 ± 85 BP; TF-1022, coral, depth 0.9 m, modern. Several samples from the Gujarat coast and the Rann of Cutch, mostly from coral samples, are dated between ca 4500 and 6500 BP. Other samples dated come from coastal plain and continental shelf environments, the latter including one sample, TF-969, in 96 m of water off Bombay, of coral dating at only 140 ± 90 BP. We look forward to the papers which will place these dates in their geological framework.

SCOTT REEF, SAHUL SHELF, AUSTRALIA: The northwestern Australian reefs are among the least known in the world, apart from a reconnaissance report by C. Teichert and R.W. Fairbridge (Some coral reefs of the Sahul Shelf, Geog. Rev. 38: 222-249, 1948). In June 1971 Australian newspapers carried reports of deep drilling on Scott Reef, 14°05'S, 121°50'E, immediately south of Seringapatam Atoll, carried out by a consortium including Woodside Oil NL, BOC of Australia, Mid-Eastern Oil NL, Shell Development (Australia), BP Development Australia, and California Asiatic Oil Co. Gas flow rates from Scott Reef No 1 well have been

reported as: 18 million cubic feet of wet gas a day from the interval 14,105-14,124 ft; 11 million cubic feet from 14,240-14,330 ft; and 9.8 million cubic feet from 14,370-14,390 ft. Exploitation of this gas field is being considered, and it is possible that a land-based production installation could be based on a small island on Scott Reef. The lagoon with a depth of 20 fathoms could be used as an anchorage. In view of the lack of knowledge about these reefs, it is to be hoped that these developments will provide an opportunity for thorough faunal and floristic studies of Scott Reef (including land areas) before development begins. These details of the Scott Reef well appeared in The Australian for 9 and 16 June 1971.

TONGA: The Oct. 7 issue of the Tonga Chronicle announces the initiation of oil drilling with great fanfare at Ma'ufanga, Tongatabu. It is with mixed feelings that we read this. We are, of course, sympathetic to the Tongans' desire for prosperity, and we are interested in what will be learned about the subterranean structure of Tongatabu. On the other hand, we have seen what oil strikes have done to other societies, including some regional branches of our own, and we would be most unhappy to see one of the few still truly viable Polynesian cultures destroyed by too sudden prosperity and "development." We hope that, at least, the agreement between the Tongan Government and the Tongan Oil Participants calls for full publication of the scientific results of the drilling, that cores will be taken, and that provision is being made for their scientific examination and study. We are happy to offer the pages of the ARB for publication of any scientific observations that result from this enterprise.

SEYCHELLES: The Government of the Seychelles has just published a "white paper" setting forth the current government policy on conservation matters in the Archipelago. This 10-page document is obtainable from the Seychelles Ministry of Agriculture, Natural Resources and Marketing, Victoria, Mahé, Seychelles, for 3 shillings.

The paper summarizes the present conservation legislation and explains the plans of the government to implement these regulations and to introduce additional provisions where necessary. The plans are largely based on a report by Mr. J. Procter, who spent some months studying the situation in detail. The government has, in most respects, accepted the recommendations of the Procter report.

We need not go into any detail on what is planned, as anyone interested will certainly send for the document itself. It is a satisfaction to be able to congratulate the Seychelles Government on their plans for the protection of what is left of the magnificent land fauna and flora of the islands, and especially to commend their being ahead of most of the rest of the world in establishing marine parks. The intent to prohibit spear-fishing is an encouraging development that could well be emulated elsewhere.

The recent opening of the new international jet airport on Mahé makes this firm set of policies on conservation especially timely. In order to support a lasting tourist trade, the Seychelles will have to have, over the long pull, something to offer beside novelty and remoteness. The natural features, both marine and terrestrial, provide this. To properly utilize them, an active program to study and make known the island natural history is essential. There is a rumor that Mr. Procter will return to the Seychelles as conservation officer. If true, this will give him an opportunity to help implement this program for which he is largely responsible.

SOOTY TERN STUDIES IN THE SEYCHELLES: For some time concern has been expressed about the exploitation of Sooty Tern eggs in the Seychelles, the scale of which has led to a reduction in the sizes of some colonies (see, for example, M.W. Ridley and R. Percy: The exploitation of sea birds in Seychelles, Colonial Res. Stud. 25: 1958). Dr C.J. Feare, of the University of Aberdeen, has now been given a grant by the Natural Environment Research Council for a three-year study of the problem, beginning in 1972. The aims of the study are to collect basic data on the breeding output of the birds, and to lay the foundations for longer-

term work which will permit the construction of mathematical models of the population dynamics of the species in the Indian Ocean. From the results a rational plan of exploitation will be formulated.

During the first season the general breeding biology will be studied in order to discover the causes and extent of natural losses within a colony, and how these vary in different parts of the colony and at different times in the season. The second year will be devoted to observing the effects of experimental removal of eggs on the overall output of the colony.

The results of these investigations will provide a basis for the work of the third season, in which Sooty Tern colonies in the Seychelles will be counted, and recommendations made for the modification (if necessary) of existing regimes of commercial exploitation, in order that the futures of both the tern colonies and the egg industry will be assured.

DUCIE ATOLL: As a part of his long-term investigation of the marine mollusk fauna of Polynesia, Dr Harold Rehder, on Jan. 13-15, 1971, visited little known Ducie Atoll, between Pitcairn and Easter Islands, perhaps the most remote and isolated of all coral atolls. Notable was the fact that the forest on Ducie is composed of only one species of tree, *Tournefortia argentea*. Rehder gave a lecture on the impoverished biota of this atoll at the National Museum of Natural History on Feb. 10, 1972. We hope to be able to offer our readers a description of Ducie by Dr Rehder in the near future.

FANNING ISLAND EXPEDITION: Under the auspices of the Hawaii Institute of Geophysics, a group of 26 scientists and students from the University of Hawaii and the B.P. Bishop Museum spent over three weeks on Fanning Island doing scientific investigations of great diversity. This atoll was the site of one of your editors' (F.R.F.) introduction to coral atolls, some 38 years ago, so this expedition is of extra special interest to him. The leader of the party was the eminent geologist, Prof. Keith E. Chave. Support was provided by the National Science Foundation.

That the visit was a most productive one is shown by the massive report, HIG-70-23, published in November 1970, and a fine series of papers in the April 1971 issue of Pacific Science (25: 188-289). The papers in the report and in the Pacific Science number dealing with land aspects have been listed and annotated in the Supplement to Island Bibliography, recently published. The marine papers, by far the majority, are listed in the "Briefly noted items" section at the end of the present Island News and Comment. The University and Keith Chave are to be congratulated on this achievement.

MEETINGS: *The Regional Symposium on Conservation of Nature - - Reefs and Lagoons*, organized and hosted by the South Pacific Commission in collaboration with the International Union for Conservation of Nature and Natural Resources, took place in Noumea, Aug. 5-14, 1971.

During the first days, the territorial representatives described and discussed the problems of their territories, of which unfortunately only a limited number were represented. It became quickly apparent, then and later in the more general Symposium starting on Aug. 9, that lagoon pollution, reef destruction and other conservation problems are not uncommon in Pacific island territories and are in fact rapidly becoming alarming in many of them. Twenty-one resolutions on the protection of reefs and lagoons and on more general topics were adopted and addressed to the SPC and governments and administrations concerned. They are published as a supplement to IUCN Bulletin 2(21): Oct.-Dec. 1971. A large number of mimeographed background papers, and draft proceedings, were available at Noumea.

Planned utilization of the lowland tropical forests. A symposium sponsored by the Indonesian Institute of Science (LIPI), the Regional Center for Tropical Biology (BIOTROP) and Unesco was organized by the Standing Committee on Botany of the Pacific Science Association at

Tjipajung Indonesia, Aug. 12-14, 1971. It included one session on Pacific Islands forest conditions. A report on this meeting, by Prof. D. Mueller-Dombois, appears in Nature and Resources, a newsletter published by Unesco, 7(14): 18-22, Dec. 1971.

Twelfth Pacific Science Congress, Canberra, Aug. 18-Sept. 3, 1971. The Noumea and Tjipajung symposia were pre-congress meetings and many of the participants went on to Canberra where the Australian National Academy organized the congress at the Australian National University. A report on the Congress is available in the Pacific Science Association Information Bulletin 23 (3-5): Oct. 1971. This includes portraits of the recipients of honors and awards announced at the opening session: Dr Sarwono Prawirohardjo and Sir Maurice Yonge were made Honorary Fellows of the Association, Dr Carl L. Hubbs received the Shinkishi Hatai Medal and Dr F. Raymond Fosberg the Herbert E. Gregory Medal for distinguished service to science in the Pacific. The 13th Pacific Science Congress will be held in Vancouver in 1975, at the invitation of the National Research Council of Canada.

M.-H.S.

The International Symposium on Coral Reefs (see ARB 148: 8) sponsored by the Great Barrier Reef Committee with the Committee for International Symposia on Corals and Coral Reefs is to be held at Heron Island and other locations on the Great Barrier Reef, tentative dates are now 29th May-10th June 1973. Address inquiries to Dr. G.R. Orme, Dept. of Geology and Mineralogy, University of Queensland, St. Lucia, Q4067, Australia.

PLANTS OF OCEANIA: Botanists interested in Pacific island floras will be glad to learn that the vast accumulation of unmounted island collections in the Paris herbarium, long in storage, are being sorted to family and made accessible to visiting botanists. Mr. N. Hallé, Sous-Directeur, Laboratoire de Phanérogamie, has undertaken the immense task of sorting through this accumulation of 150 years. He is willing to make available to serious workers material in any family, providing the botanists intending to visit the Paris herbarium will inform the Directeur of the Laboratoire de Phanérogamie, 17 rue Buffon, Paris V^{e}, France, of their planned visit and their needs sufficiently in advance.

ISLAND SCIENCE NEWSLETTERS: A number of informal serial publications have been established that deal wholly or in part with scientific affairs on islands or with matters of interest to island scientists. Several of these will be listed, with their sponsoring organizations and addresses and editors if known. We will not usually repeat news items that appear in these newsletters, unless they seem of unusual importance to our readers.

The Elepaio. Hawaiian Audubon Society, eds. Miss Charlotte Hoskins and Miss Unoyo Kojima, P.O. Box 5032, Honolulu, Hawaii 96814, U.S.A.

Newsletter of The Hawaiian Botanical Society, c/o Dept. of Botany, University of Hawaii, Honolulu, 96822, ed. Russell K. LeBarron.

Aldabra Newsletter. The Royal Society, 6 Carlton House Terrace, London, S.W. 1, England. Requests to be placed on the mailing list should be sent to Dr. D.R. Stoddart, Dept. of Geography, Downing Place, Cambridge CB2 3EN, England. He also keeps a mailing list of those persons interested in exchanging publications, especially in the fields of terrestrial and marine ecology of tropical oceanic islands and coral reefs, for reprints of papers on Aldabra forming a series entitled Contributions from the Royal Society Aldabra Research Station.

Association for Social Anthropology in Oceania Newsletter, ed. Bob Kiste, Center for South Pacific Studies, University of California, Santa Cruz, Calif. 95060, U.S.A.

The Palaeontological Association Circular, ed. Dr. J.A.E.B. Hubbard. Geology Dept., Kings College (London University), Strand, London, W.C. 2, England.

Environmental Sciences Quarterly Newsletter, Office of Environmental Sciences, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

CITRE Newsletter, ed. Stephen Smith, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

An Environmental Newsletter, Caribbean Conservation Association, c/o Caribbean Research Institute, College of the Virgin Islands, St. Thomas, U.S. Virgin Is. 00801.

Pacific Island Program Bulletin, Dept. of Anthropology, University of California, Los Angeles, Calif.. 90024, U.S.A. (This bulletin ceased publication with no. 15, Oct. 20, 1971).

News and items of current interest are also reported in the *Pacific Science Association Information Bulletin,* Miss Brenda Bishop, ed., Bishop Museum, P.O. Box 6037, Honolulu, Hawaii 96818, and *Cahiers du Pacifique* usually include sections on News, Meetings, and Congresses, and bibliographies. No. 15, Sept. 1971, received in Washington in early 1972, includes such a section of "Nouvelles du Pacifique" of 74 pages, by J. Plessis. Address for the Cahiers: Fondation Singer-Polignac, 43 Ave. Georges-Mandel, Paris 16e.

ISLAND BIOLOGICAL STATIONS:

West Indies Laboratory: In July 1971 classes opened at the new West Indies Laboratory of Fairleigh Dickinson University at Teague Bay on St. Croix Island, U.S. Virgin Islands. Starting with a magnificent physical plant, though modest in size, including laboratory and library buildings, dining hall, living quarters for students, staff, and visiting research workers and faculty, a pier and boat house, shop, sewage treatment and recycling plant, and warehouse, this tropical station has immediately taken its place as one of the finest combination teaching and research facilities in the Caribbean. The director is Prof. H. Gray Multer, the resident scientist is Dr John Ogden, and the manager is Mr. Lowell Bingham. Courses in geology, ecology, zoology, botany and marine biology are offered. During periods when no regular classes are scheduled the laboratory is available for use by classes from other universities by arrangement with the director. Arrangements also may be made for use of the facilities by visiting investigators. A brochure is available on request. The address of the station is West Indies Laboratory, P.O. Annex Box 1010, Christiansted, St. Croix, U.S. Virgin Is. 00820.

University of Guam Marine Laboratory: The new marine science facility of the University of Guam opened on January 15, 1971, in a well-equipped building, beautifully situated on Pago Bay, east coast of Guam, just below the University campus. Flowing sea-water, boats, diving gear and other equipment for marine biological studies are available. Prof. Lucius G. Eldredge is director and will supply information on request. The address is Marine Laboratory, University of Guam, P.O. Box EK, Agaña, Guam, 96910, U.S.A.

The University Marine Biological Station, Millport, Isle of Cumbrae, U.K.: This station, formerly known as the Marine Station at Millport, is now functioning under new auspices, controlled by the Universities of London and Glasgow. Its objectives are teaching and research in marine biology. The director is Prof. Norman Millett, formerly Professor of Zoology at Bedford College, University of London. Besides courses offered by the station, accommodation will be provided for outside classes accompanied by their own teachers.

Royal Society Research Station, Aldabra: The Royal Society has announced the appointment of Dr David Wood as the new director of the station. The lease of the island, formerly held by H.Savy and Co., Ltd., of the Seychelles, has been assigned to the Royal Society. The purchase of this lease was in large part made possible by a donation from Mr. Christopher Cadbury. Detailed news on Aldabra research activities will be found in issues of the Aldabra Newsletter and in press releases from the Royal Society, 6 Carlton House Terrace, London, S.W. 1, U.K.

Antenne de Tahiti: The Muséum National d'Histoire Naturelle of Paris has recently established an outpost or "antenna" in French Polynesia. There will be a small station on Moorea, and research plans for 1972 include studies on Rangiroa, Bora-Bora, and Taiaro Atoll. The director is the very active malacologist, Dr Bernard Salvat of the Muséum (55 Rue de Buffon, Paris 5), and the mailing address of the station is B.P. 562, Papeete, Tahiti, French Polynesia.

RECENT DEATHS:

Edwin C. Allison: Ned Allison died suddenly on Jan. 1, 1971. He was struck down while guiding students on a fieldtrip, near Caborca, Sonora, Mexico. His work was mostly in paleontology, but he also collected and studied living forms, especially mollusks. He took part in the 1958 Scripps Institution expedition to Clipperton Island and published several papers on the mollusks with L.G. Hertlein. He was a gentle and patient colleague in the field, and generous in exchanging information or photographs later. Of some comfort to his friends and colleagues, as well as his family, is the fact that San Diego State College has announced that there will be an Edwin C. Allison Center for the Study of Pacific faunas in the Department of Paleontology where he taught.

Richard J. Russell: Dean Russell died on September 17, 1971, at Baton Rouge, Louisiana at the age of 75. Coastal geology and geomorphology thus lost one of its most active and distinguished leaders. Not only through his own research did he advance his science, but even more through the students and younger colleagues that he helped and encouraged. His Coastal Studies Institute at Louisiana State University is one of the most important centers for the study of coastal geomorphology. We sincerely hope that, even without Russell's leadership, it will continue to be outstanding and productive in this fascinating field of research.

SHORT PAPERS

NOTES ON THE HERPETOFAUNA OF KUME-JIMA AND O-JIMA, RYU KYU ISLANDS

by Clifford Ray Johnson
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Kume-jima, the westernmost island of the Okinawa Group, covers 26 sq. miles and lies 55 miles W of Okinawa in the East China Sea. Like most of the Ryu Kyu Islands, it is subtropical with a mean annual temperature of 72°F, average humidity of 80%, and a mean annual rainfall from 51 to 91 inches. O-jima lies 1 mile S of Kume-jima and has an area of about 1 sq. mile.

The islands appear to be of volcanic origin with a shoreline composed of disintegrated corals and conglomerates. Kume-jima is forested, like Okinawa, in montane regions and cultivated along the coastal areas. O-jima is entirely cultivated. Both islands were by-passed by World War II.

The herpetofauna of Kume-jima, although one of the larger islands of the Okinawa Group, is very poorly known. During March 1965, I visited Kume-jima and O-jima and made small collections of reptiles and amphibians over a period of five days. The only previous mentions of Kume-jima in the literature are by Koba (1959) and Okada (1966).

Rana limnocharis Boie (in Weigmann)

Four specimens were collected near Gima in a cultivated field. They appeared similar to specimens from Okinawa where this is the most abundant species of ranid (Johnson, 1969).

Rana namiyei Stejneger

A single specimen, 85 mm snout-vent length, was capturednear a rice field close to Gima. This species on Okinawa is usually restricted to montane areas, but appears to be more eurytopic on Kume-jima.

Eumeces margenatus (Hallowell)

One specimen was collected at the edge of a cultivated field in dense brush near Gima. Another was seen in a similar habitat near O-village, O-jima. None were seen along the beaches, although they were often found in such habitats on Okinawa.

Ateuchosaurus p. pellopleurus (Hallowell)

One specimen, 42 mm snout-vent length, was collected near Gushikawa in a grass field.

Takydromus smaragdinus Boulenger

Three specimens were collected in thick grass adjacent to a cultivated field near Gima.

Trimeresurus okinavensis Boulenger

One specimen was seen in a grass field on Mt. Uegsuka. According to the natives these snakes are common throughout the island. Other species of *Trimeresurus* may also occur on the island.

The following is the most complete check-list to date of the herpetofauna of Kume-jima based upon my collection and those of Koba (1959).

Order Salientia

Microhyla ornata (Duméril and Bibron)
Rhacophorus viridis (Hallowell)
Rana limnocharis Boie (in Weigmann)
Rana namiyei Stejneger

Order Sauria

Eumeces margenatus (Hallowell)
Ateuchosaurus p. pellopleurus (Hallowell)
Takydromus smaragdinus Boulenger

Order Squamata

Trimeresurus okinavensis Boulenger

ACKNOWLEDGEMENTS

I wish to thank Cdr. William F. Russell, CEC, USN, for his cooperation during field operations and Rev. and Mrs. Kanard for extending their hospitality during my stay on Kume-jima. Transportation was arranged by the U.S. Navy. Dr Harold F. Heatwole, The University of New England, reviewed the manuscript.

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LAYSAN ALBATROSS AS CARRIER OF FLOATING DEBRIS TO LAND

by Miklos D.F. Udvardy
Sacramento State College, Calif.

Upon reading Kenyon and Kridler's interesting note (Laysan albatrosses swallow indigestible matter, The Auk 86: 339-343, 1969), I found that my own observations on Laysan might modify the impression these authors gave about the carrying ability of albatrosses and the hydrography of that island.

During two expeditions to Laysan Island (see notes in Elepaio 20: 16, 1959; 22: 43, 1961, and in ARB 103: 1964) my own experience with juvenile and adult albatross skeletons was by and large similar to that of Kenyon and Kridler: the carcasses and skeletons we found were also lined with pumice, armoured fish, kukui nuts and other indigestibles though plastic artifacts were not observed by us.

Kenyon and Kridler note that the "Lagoon" of Laysan Island is not connected by any channel with the sea (i.e. it is, in reality, a lake) and therefore they conclude that the plastic and pumice they found deposited at high water line of the lagoon must have originated from contents of albatross carcasses. But this conjecture needs to be modified: some, but not *all*, the former floatsam on the perimeter of this lagoon originates with the albatrosses. An undeterminable portion of the debris--and certainly all large-sized pieces, too big for albatrosses to swallow--should rather be assumed to have been brought in by the huge waves of winter storms which break through the flat coral sand area that girdles the lagoon on the south and which is only at a few places reinforced by low ridges or patches of phosphate rock. This area is devoid of a protective beach crest and here and northward up to the edge of the lagoon we found in June 1959 dozens of Japanese fishnet floats: heavy glass balls of 80 and 90 mm, or even more, in diameter, certainly unfit for albatross consumption. It is safest to assume that these glass floats were brought in by wave action. Then, other floatsam is likely to enter the lagoon the same way and the albatrosses are not the only carriers to blame for all deposited foreign material.

MOROTIRI (BASS ROCKS) AUSTRAL ISLANDS

by F.R. Fosberg
Smithsonian Institution

Morotiri or Bass Rocks is a small cluster of 4 rugged volcanic rocks and a number of stacks that form the southeast extremity of the Austral Island Group, in French Polynesia. They are located about 46 miles east by south of Rapa, at about 28°S, 143°30′W. As nothing of a general nature seems to have been published on their natural history, it may be worthwhile to publish notes made on a short visit on July 22, 1934, when Harold St. John, Elwood C. Zimmerman and I landed on the largest of the rocks and collected what could be found and

reached in a couple of hours of scrambling and climbing over guano-covered ledges and cliffs.

The highest of the rocks is about 100 m high and not much more than that wide, several times as long. The rocks were practically without a real covering of vegetation. A sparse growth made up of *Cyperus, Bidens, Digitaria* and *Portulaca* was present on the non-perpendicular slopes and ledges, almost luxuriant in favorable spots. In the crevices in the rocks *Asplenium, Nephrolepis,* and *Cheilanthes* formed tufts. *Solanum nigrum* was present here and there. *Lycium* was seen on the lowest slopes, and a prostrate *Euphorbia* formed mats on one slope on one end of the island. A sterile rosette of *Sonchus* was seen.

Some of the rocks were sparsely covered with lichens. A sterile moss was occasional around seeps. These seeps were evidently highly charged with lime or some other substance that crystallized out around the cracks.

Under the plants and stones was a remarkably large fauna of insects, spiders, centipedes, and isopods. Of the last, 3 species occurred under stones and a species of *Ligia* ran around over rocks, collecting in numbers under overhanging rocks. At least 1 species of centipede, 4 or 5 of spiders, 1 or 2 of ticks, 2 of mites, 1 of *Lepisma,* 1 of *Machilis,* 2 of Collembola, 1 cricket, 1 or 2 of ants, 1 lygeid, 4 species of *Rhynchogonus,* and 1 other weevil all lived under stones and plants. Two or 3 kinds of flies and 2 of moths were seen flying. A louse fly (*Olfersia* sp.?) was abundant on shearwaters.

Birds were more than abundant, but nearly all belonged to a species of gray tern and 2 or 3 of shearwater. A couple of white-tailed tropic birds were seen. The shearwaters were nesting and eggs and young were abundant on small ledges and between tufts of sedges. Burrowing would be difficult here.

The rock is composed of more or less bedded basalt, forming a high core in the center, and the two ends are capped with tilted beds of what is probably tuff (described as "apparently sedimentary rock" in my notes at the time).

No coral was seen. Encrusting calcareous algae colored the lower rocks. Non-calcareous algae were reasonably abundant but badly beaten to pieces by wave action. The waves, even at the "quiet" period of our visit, were several meters high, making landing hazardous, to say the least. Acorn barnacles and chitons were seen on the lower rocks.

Fish of many kinds were abundant in the area and many were caught while the ship cruised around the area near the rock while we worked.

SOME LAND BIRD MIGRANTS IN THE WESTERN INDIAN OCEAN

by C.W. Benson

Mr. H.H. Beamish has shown me a colour slide of a bird photographed by him in November 1970 on African Banks, Amirante Islands, at ca. 5°S, 53°E (for an account of the geography and ecology see Stoddart & Poore, ARB 136: 187-191, 1970). Undoubtedly the bird is a *Phylloscopus* species, and on geographical grounds by far the most likely is the Willow Warbler, *P. trochilus,* from which the bird on the slide was indistinguishable. On the African mainland this species is abundant during the palaearctic winter, even reaching as far south as South Africa (Mackworth-Praed & Grant, African handbook of birds, Ser. I, Vol. 2: 1955). According to the same authors, the Chiff-Chaff, *P. collybita,* not certainly distinguishable on the evidence of this slide from *P. trochilus,* migrates almost as far south as the equator, but its occurrence on African Banks seems extremely unlikely. As far as I am aware, this is the first record of a palaearctic breeding sylviid from any island in the western Indian Ocean south of the equator. Indeed

Ripley and Bond (Smiths. Misc. Coll'ns. 151(7): 1966) do not even give any such record from Socotra, although they quote single old records each of *P. collybita* and the Whitethroat, *Sylvia communis*, from Abd-el-Kuri, between Socotra and Cape Guardafui.

Among records of birds received by the Royal Society from J.A. Stevenson on Aldabra, copies of which were transmitted to me by D. Griffin, the following from West Island should be mentioned:

Eurystomus glaucurus, Broad-billed Roller: One seen at 15:00 hrs. on 20 October 1970. Benson and Penny (Phil. Trans. Roy. Soc. B260: 517, 1971) give but few records from Aldabra and neighbouring islands.

Oenanthe oenanthe, European Wheatear: One seen at 15:00 hrs. on Wed. 27 January 1971, with a note that there had been a cyclone the previous week. What was presumably the same individual was seen again on 1 and 5 February 1971. Benson and Penny (*op. cit.*: 519) suggest that this species may winter regularly on Aldabra in very small numbers.

HURRICANE LAURA, WITNESSED IN BRITISH HONDURAS

by Arnfried Antonius
Smithsonian Institution

Hurricane Laura was first reported on Sunday, November 14, 1971, in the morning. It was then a mere tropical storm near Swan Island, but in the afternoon it reached hurricane force and was baptized Laura. During the following days Laura first travelled N in the direction of Cuba, then turned W and finally S along the coast of the Yucatan Peninsula. It entered British Honduras territory in the early morning of November 20. By about mid-afternoon the hurricane had passed Belize, with wind speeds about 70 knots and thus not doing any harm. In Stann Creek though, things were slightly different. Belize and Stann Creek lay both on the western rim of the hurricane, but as it moved more and more southwesterly, the eye came closer to Stann Creek. Winds blew during the day first from the W, then NW, N, NE, and in the afternoon from the east. The eye was closest then. The winds came from the open sea and reached at least 80 knots. About half the harvest was lost in the extensive Citrus plantations east of Stann Creek, and wave action removed the longest wooden pier of the area.

On Glover's Reef, winds first came roughly from the W with speeds up to 70 knots. Wave action piled up large heaps of *Thalassia* and algae along the lagoon side of the cays without doing damage. The eye passed around noon, creating a two-hour lull. The most violent stroke came after this, with sudden wind forces of 80-100 knots from the NE; this lasted only a few minutes and calmed down to 70-80 knots shortly afterwards, but during this brief time some damage was done to the facilities of a diving resort on Long Cay. The winds sank a 35-foot vessel, blew down one of eight existing cottages, and removed half the tin roof of another hut. Very few coconut trees fell. Underwater, on the eastern and northeast fore-reef slope, broken trunks of *Acropora palmata* up to 20 cm in diameter could be observed here and there, as well as large colonies of *Acropora palmata* and *Diploria strigosa* turned upside down. However, only 2 m to the right or left of them, it was possible to find much younger colonies, very fragile and yet completely unharmed. Therefore, the character of the turbulence must have varied considerably within a space of a few meters.

In the evening, Hurricane Laura was in the Monkey River area and it dissolved and disappeared during the night south of Punta Gorda. Hurricane Laura was at least 100 miles in diameter, slow moving and of moderate force.

In its wake, Laura dragged along the windy, cool and rainy weather of a proper "Norther." The heavy rainfall during the night and during November 21 caused extended inundation in the flat coastal areas of British Honduras and made some of the most important roads impassable. A zone several hundred meters wide of brown muddy water along the British Honduras coast made the freshwater influx clearly visible, the major rivers causing extensive protrusions of this discoloration to almost half way across the barrier reef lagoon.

In conclusion, it can be stated that Hurricane Laura was an unusually late Hurricane, followed by an unusually early "Norther." Fortunately, the overall effects of both on British Honduras can be considered negligible.

PUBLICATIONS

REVIEWS:

Westoll, T.S. and Stoddart, D.R. (organizers), 1971. A discussion of the results of the Royal Society Expedition to Aldabra 1967-68, Philosophical Trans. Royal Soc. London, ser. B, 260 (836): 654 p. £19.00, $50.00. It is a curious fact that two of the most intensively studied atolls in the world were investigated for entirely different reasons. Bikini, in the Pacific, was investigated twenty-five years ago to evaluate the destructive power of atomic bombs. Now, Aldabra, in the Indian Ocean, is being given similar treatment in a laudable attempt to save it from the effects of encroaching civilization.

Aldabra, an atoll that rises from the deep sea, is the last undisturbed elevated reef island in the Indian Ocean. Its continued existence in this category was threatened in 1965 when the British Ministry of Defence announced a plan to construct a Royal Air Force Staging-Post there for planes flying to the Far East. In addition to a landing strip, the plan called for the construction of a harbor for tankers, a road, and a radio transmitting station. Realizing that such construction would probably have a devastating impact on the island and its unique fauna, the Royal Society, on behalf of scientific and conservation organizations, dispatched in 1967 a scientific expedition to study the island. In that same year the military plans were abandoned for financial reasons but the Society wisely continued its studies in the hope that the establishment of a scientific research station on the island would give protection to the area in the foreseeable future. The present volume presents Aldabra's case in a most impressive manner.

In September 1966 D.R. Stoddart and C.A. Wright had accompanied the survey party that went out to reconnoiter the island as a potential staging-post and radio station site. Stoddart was named a member of the Aldabra Research Committee set up by the Royal Society to work with personnel from the Smithsonian Institution, the U.S. National Academy of Sciences and the University of the Witwatersrand in a lengthy research program. Stoddart became the overall expedition leader and is the author, or co-author, of a number of the papers in the present volume. To date, more than forty persons have participated in the expeditions to Aldabra.

The biota of Aldabra is an interesting one that is intermediate between that found on sea level atolls and that of the high islands. It has many remarkable features. It supports, for example, an estimated total of 100,000 Giant Land Tortoises; it is the land base for several kinds of marine turtles; the largest colony of frigate birds in the Indian Ocean (30,000) breeds there. The island is the home of several distinct species and subspecies of land birds. One of these, a new warbler, was discovered during the present investigation; another is the rail, *Dryolimnas*. This is the last of the flightless birds of the western Indian Ocean but at least 1000 still survive on Aldabra.

Aldabra is a very small island. The overall area is only 365 square kilometers, the land area about 40 percent of the total. Bikini, with an overall area of more than 700 square kilometers, is nearly twice the size of Aldabra, but Bikini's land area is only about 10 percent of its total.

Aldabra was probably discovered during the earliest years of the 16th Century but it remained uninhabited by man for about 400 years. Scientific studies of several sorts have been made at Aldabra over a period of nearly 100 years and many of the early visitors made large collections of plants, insects and birds. An ecological survey of Aldabra and nearby islands was made by Fryer in 1908 and Aldabra became one of the better known reef islands of the Indian Ocean. Not much additional work was done in the sixty years that followed-- not until the activity that grew out of the recent crisis.

The present quarto volume with more than 650 pages and many excellent illustrations is an elaborate and satisfying treatment of many aspects of Aldabra and its life. It consists of two dozen reports. These give many data that support a series of earlier papers that presented the bare essentials of what came to be known as "The Aldabra Affair."

A summary of earlier scientific studies at Aldabra and neighboring islands is followed by a series of reports dealing with the physical environment--the geomorphology, climate, tides, and shallow water environments. These studies set the stage for reports that deal with the existing flora (ground covers, mangroves, terrestrial and freshwater algae) and fauna (invertebrate and vertebrate). Among the invertebrates, special treatment is given to the ostracodes, the freshwater snails, insects and decapod crustaceans. Among the vertebrates, the tortoises, sea turtles, and birds (land birds, migrant waders and sea birds) are fully treated and a report on bats is included. Both reptiles and birds were examined for blood parasites. Some of the reports are short and admittedly preliminary, but all are well organized and offer a sound foundation for future work. In addition to the subjects already mentioned, there is a special report on the origin and distribution of the flora of Aldabra and an analytical study of the evolution of terrestrial faunas in the western Indian Ocean.

It is surprising and certainly most gratifying that Aldabra has remained almost completely undisturbed during a lengthy and not entirely uneventful history. Commercial exploitation has been only sporadic. Unlike its three neighboring islands, Assumption, Cosmoledo and Astove, Aldabra has never been the site of serious mining operations for guano. The fact that rainfall on Aldabra is small and erratic and that areas of sandy soil are very limited has forestalled development of coconut growing. The fisheries potential is not great in the lagoon or in the waters outside. The Giant Tortoises make a profitable export but this traffic is controlled.

Aldabra is the largest of a group of four islands. It has a maximum height of 8.8 meters but still retains its atoll configuration--a rim encloses a shallow lagoon with three entrances, two of which are deep channels. Large parts of the rim consist of jagged cavernous limestone (champignon) that is covered by dense scrub. Small areas (14 percent of the land area) at the eastern end are smoother and flatter (platin); they support a more open vegetation and furnish a home for the tortoises, frigate birds, and other species.

Solution surfaces and residuals are described in fair detail. Some are satisfactorily explained but others remain problematical. There is wide lateral facies variation in the elevated limestones and it is not possible at present to make island-wide stratigraphic correlations. Thus, the chronological framework of the limestones remains uncertain. Some Carbon-14 determinations have been made on *Tridacna* and *Chama* shells in the limestone; more are awaited.

The report on geomorphology is a joint effort involving four investigators. It discusses the topography and morphology of Aldabra itself, but these discussions are preceded by a wide-ranging summary of the regional setting that prepares the reader for a sketch of the probable evolution of the island. This is an interesting story but the authors recognize that it is by no means a final account. D.R. Stoddart, the senior author of the report on geomorphology, has informed this reviewer (written communication March 27, 1971) that subsequent work points to a much more complex picture. Studies of the limestone outcrops have revealed half a dozen transgressions and regressions and a large land fauna. Uranium dates at 125,000 years have also been obtained; these markedly older than the equivalent C^{14} dates.

The report on geomorphology deals only with the surficial features of Aldabra. The investigators hope, however, that, following additional geophysical work (magnetic, gravity and seismic) they can carry out a drilling program that will determine the nature and age of the atoll's foundation and reveal the major steps in its geologic history. The geophysical surveys will not injure the existing environment but the drilling would present a hazard and probably should be done on nearby Assumption Island. Deep drilling could establish a standard stratigraphic section for the western Indian Ocean comparable to that set up for the western Pacific by drilling in the Marshall Islands.

The work done to date has resulted in a fairly complete inventory of the fauna and flora existing on Aldabra. This includes a determination of the importance of exotic elements present. The time has now arrived to draw up a program for a Research Station that will preserve the rich values now in existence while studying the structure and functioning of the ecosystem. Future investigations will include dredging in the waters surrounding the atoll but this will in no way injure the existing environment.

The threat of exploitation has diminished because of economic reasons but it could be reactivated at a later date. Meanwhile, the excellent preliminary investigations are continuing and it is hoped that they will furnish any additional information that may be needed by the conservationists in their effort to save undisturbed Aldabra as a nature reserve and scientific research station.

Harry S. Ladd

Basilewsky, P., ed. 1970. La faune terrestre de l'île de Sainte-Hélène. Ann. Mus. Roy. Afr. Centr., Zool., 181: 1-227.

This informative volume is the first in an anticipated series stemming from two expeditions (1965-66) dispatched to St. Helena by the Musée Royal de l'Afrique Centrale of Tervuren, Belgium, to intensively collect the land and fresh water fauna of this ecologically devastated tropical south Atlantic island. Especially arresting is a series of excellently reproduced photo plates of a barren, weedy landscape, and tiny vestiges of native forest. Four introductory chapters, with maps, afford useful background on the present status of the island and its biota: Geography and climatology by N. Leleup; "Geological history of St. Helena in relation to its floral and faunal colonization" by Ian Baker; Vegetation by J. Decelle; a history of faunal exploration and study by P. Basilewsky and P.L.G. Benoit; and an account of the Museum's expeditions to the island with notes on collecting stations by Basilewsky and Decelle.

Animal groups systematically treated are: Vertebrates, largely sea birds, by Basilewsky; and eight orders of insects by specialists of several nationalities. Many new records and several new insect species attest the heretofore scant knowledge of a fauna already much depleted. The insect groups treated are Collembola, Diplura, Thysanura, Odonata, Blattaria, Isoptera, Orthoptera, and Dermaptera.

Bryce Decker

Yoshino, M.M., ed. 1971. Water balance of Monsoon Asia - - a climatological approach. Honolulu, University of Hawaii Press, 1-308. $16.00. This handsomely produced volume comprises fifteen contributions, by as many Japanese authors, on the water balance and related atmospheric phenomena of Monsoon Asia and adjacent regions including the islands of Indonesia, northern Indian Ocean and the west and southwest Pacific.

Yoshino's introductory review of water balance problems and historical background is followed by four sections that take up sources and transfer of water vapor from season to season; distribution of precipitation, cloudiness and precipitable water during the summer monsoon; secular variation of precipitation and climatic change; and finally applications of several climatic classifications. There are many excellent maps and diagrams, the English is unstilted, and the bibliographies will be of interest for the access they afford to Chinese and Japanese literature on climate and weather.

Bryce Decker

Veevers-Carter, W. D. 1970. Island Home. 1-345, Random House, New York. Most of us know coral atolls from expeditions and short visits only. We hurry frantically to collect what we can and write what notes we can in the short time we have. We miss some of the essence of life in these microcosms. Our friend Wendy Veevers-Carter lived on one tiny 65 acre coral island, Remire, of the Amirante group in the Western Indian Ocean, for three years. One might expect that she had infinite leisure to soak up the essence of island life - - but the book gives quite the opposite impression. She was so continuously busy that one wonders when she had time to write the book. Essentially this is an account of human relations, of an effort to understand and deal with the entirely different pattern of behavior and set of mores and ethics of the Seychellois laborers. To the reader's continual great surprise the author pulled it off astonishingly well. And in telling the story she also succeeds in giving an idea, at least, of the coral island environment. The book is fascinating reading and recommended to anyone who has ever had the yen to run away and live on a tropical island. F.R.F.

Wodzicki, K. and Laird, M. 1970. Birds and bird lore in the Tokelau Islands. Notornis 17: 247-276. This small group of atolls is well on its way to becoming one of the better-known of atoll archipelagoes, largely due to the investigations and publications of the authors of this paper and their colleagues in the rat and mosquito control projects carried out between 1958 and 1970. The present paper lists the bird species observed and collected and provides one to several paragraphs of observations of various sorts on each, largely descriptive and ecological, with native names and data on use of the birds as food. Several native folk tales about birds are placed on record. Occurrence, behavior, zoogeography and conservation problems are discussed. A bibliography of 44 items (not all on Tokelau birds) is provided, as well as maps of the atolls with place names. F.R.F.

Bloom, A. L. 1970. Paludal stratigraphy of Truk, Ponape and Kusaie, eastern Caroline Islands, G.S.A. Bull. 81: 1895-1904. The author interprets the swampy coastal plains, with their 2-3 m of peat, as resulting from shore line progradation during a period of rising sea-level, slowing down about 4100 years ago. These flat benches have been regarded by many workers as evidence of a recent 1-2 m emergence, which has been considered to fit nicely with 2 m elevated reefs and notches in various parts of the world. The facts reported in Bloom's paper add to a growing body of evidence contrary to this presumed eustatic fall in sea level. To reconcile these contrary indications, and account for the biological phenomena, which have been hiterto explained in terms of eustatic 6 foot and 11 foot benches, will be the next task of geomorphologists interested in coral reefs and islands. Nine samples of highly organic sediments yielded radiocarbon dates between 1000 and 6500 years B.P. for deposition of the peat they represent and were from depths of 5 to over 20 m in the swamps. F.R.F.

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Tsuda, R.T. 1971. Status of Acanthaster planci and coral reefs in the Mariana and Caroline Islands, June 1970 to May 1971. Univ. Guam Marine Lab. Techn. Rept. 2: 1-27. This brochure is a collection of resurvey reports of the crown-of-thorns starfish situation on the reefs of Truk, Kapingamarangi, Saipan, Tinian, Aguijan, Guam, Rota, Yap, Palau, Ponape, Ant, and the atolls of the central Carolines. These are mostly areas examined by the Westinghouse teams in 1969, and data are being assembled for comparison. Maps and photos accompany the reports. In some areas control measures are being undertaken with, apparently, some success (at least temporarily). Roy Tsuda is to be complimented on getting these informative reports out so promptly and satisfactorily. F.R.F.

Lemon, E. R., et al. 1969. Biology and ecology of nitrogen, Proceedings of a conference. 1-166, Nat. Acad. Sci., Washington, D.C. This book contains nothing on islands, but summarizes briefly much of what would be needed to start investigating the nitrogen ecology of coral and other islands. It is flawed a bit by some rather naive taxonomy of certain of the higher plants discussed, but presumably the taxonomy of nitrogen-fixing bacteria is better. One is led to wonder just how adequate the treatment of nitrogen biology and ecology is, since no mention is made of the role of blue-green algae in nitrogen fixing. At least the book is a good place for the beginner to start. Some of the articles have substantial bibliographies. F.R.F.

Balgooy, M.M.J. van, 1971. Plant geography of the Pacific, Blumea Suppl. 6: 1-222. Plant geography is one of the most controversy-ridden of sciences. This may be, partly, because with an amorphous and diffuse mass of information of every degree of reliability (or unreliability), plant geographers tend to choose, usually arbitrarily, very diverse techniques, parameters, and assumptions for the organization of their data. Another reason may be that after the data are organized they are not very interesting or even significant in their own right. The interest is added by what the author of the system does with them, usually by what speculations he introduces, based on them.

This admirable book is no exception to any of the above, though the author has been unusually careful in his selection of the bases for his organizational framework and unusually conservative in his speculations. One is tempted to quarrel with him on a considerable number of points, some large, most small. Many of these derive from his selection, justified at great length, of the genus as the basic unit dealt with in his investigation. A brief review is not the place to debate the propriety of such a choice. Granted this selection as a valid basis for an analysis, Balgooy has done a superb job. He has, moreover, placed Pacific botanists in his debt for compiling the enormous mass of data presented in this volume, and for determing in a generally convincing way the "distribution types" to which all recognized Pacific phanerogam genera belong. One could wish he had used the term Austral for type 7 rather than the misleading "Subantarctic", but this is a minor objection.

He has also analyzed and summarized in a thoroughly satisfactory manner all important previous essays of phytogeographical analysis of Pacific floras. This, in itself, is an enormously useful accomplishment. It also enables us to place his own phytogeographic scheme and conclusions in a far more satisfactory perspective. Our opinion is that the picture presented is a substantial advance over its predecessors. It has shortcomings, or course. These will be remedied only after a vast amount of additional collecting and taxonomic research has been done on Pacific plants, and when a means is found to weave into this picture considerations based on species and groups of species, as well as on genera. We also do not believe that such a scheme can be very sound which does not take into account the geological setting and what is known of the paleogeography of the Pacific.

We cannot refrain from a few comments on Balgooy's findings on dispersal classes and conclusions on how the island floras originated. There may be some virtue in confining assignment of genera to the five functional dispersal classes to cases where the mechanisms involved have actually been seen in operation. However, the inevitable infrequency of such observations

naturally throws most of the genera into his two catchbasket classes, those where he has no opinion on dispersal mechanisms and which are only distinguished by small versus large diaspores. The chance of actually observing a diaspore less than 3 mm in diameter being dispersed by a typhoon is remote, indeed. This does not say anything about the probable frequency of such events, however. We found no mention of the role of either typhoons or "jet-streams" in the discussion of dispersal. Without considering these agencies, in our opinion, no general conclusions on the relation of dispersal to origin of island floras are likely to mean much. F.R.F.

OTHER PUBLICATIONS:

Téthys Supplements. The Station Marine d'Endoume, of the University of Marseille, had been publishing the works of its researchers in a series of Recueil des Travaux..., which was superseded in late 1969 by a quarterly journal, Téthys. The supplements to the Recueils, devoted to the works of the Station marine de Tuléar (SW Madagascar) - - which the Endoume Station was largely instrumental in creating and equipping - - have been replaced by a "tropical Indian Ocean" series appearing as supplements to Téthys. Two of these were published in 1971. No. 1 includes a list of the contents of the 10 supplements (1962-1970) to the Recueils, with annotations in French and English, and a list, also annotated, of 75 papers on the southwest Indian Ocean published or in press in other journals. The rest of this supplement includes papers on marine life and geology of the Tuléar area and of Réunion Island, where the Endoume Station has a branch station or "Antenne." Téthys, supplement 2, is an attempt to define terms used in coral reef morphology as exemplified by the reefs of the Tuléar region. It is presented in parallel French and English columns and is generously illustrated with diagrams and photos. Both supplements are handsomely printed. M.-H. S.

Bibliographies: We have just received two more of Noel L.H. Krauss' excellent little island bibliographies, these on Ontong Java and Rennell and Bellona, all fascinating islands among the westernmost outposts of the Polynesian culture. The Ontong Java booklet has 112 items with dates ranging from 1756 to 1969. The Rennell-Bellona bibliography has 168 items. They are published as nos. 3 and 4 of Pacific Island Studies. This series is issued and deposited in selected libraries by Mr. N.L.H. Krauss, 2437 Parker Place, Honolulu, Hawaii 96822, U.S.A.

The Hawaii Institute of Marine Biology issued as its Technical Reports 20 and 21, an annotated bibliography of Kaneohe Bay [Oahu, Hawaii] and a bibliographic species list for the biota of Kaneohe Bay, both by Joleen Aldous Gordon and Philip Helfrich.

Island Bibliographies Supplement, by M.-H. Sachet and F.R. Fosberg, is available from the National Academy of Sciences for $10.50. A circular announcing its publication has been sent to those on the mailing list of the Atoll Research Bulletin. Offset reproductions of the original volume, Island Bibliographies, by M.-H. Sachet and F.R. Fosberg, may be obtained from the National Technical Information Service, Springfield, Va. 22151, U.S.A., for $6.00. Ask for document AD-738566. If you have already tried to get the reproduction of the original volume from NTIS with unsatisfactory results, try again. The difficulties seem to have been corrected and we are assured that there will be no further problem.

From the eminent Pacific historian and documentalist, Professor H.E. Maude, we have received copies of his opening and closing addresses to the Australia Unesco Seminar on Source Materials related to Research in the Pacific Area, held in Canberra, 6-10 Sept. 1971. These papers, Pacific Documentation: An Introductory Survey, and Pacific Bibliography, were not written for publication, but we certainly hope they will appear in Proceedings of this small and select Seminar, or elsewhere, without being doctored up too much, at least without loosing any of the wit and gentle sarcasm of our friend's spoken words.

Bricker, O.P., ed., 1971. Carbonate cements. 1-376, The Johns Hopkins Press, Baltimore and London. This remarkable volume reports a symposium held in Bermuda in 1969. A copy for review for the next ARB Island News and Comment number has just come to hand.

Stoddart, D. R. and Yonge, M., eds., 1971. Regional variation in Indian Ocean Coral Reefs. 1-572 (Zoological Society of London Symposia 28), London and New York. We have also just received a copy of this for review for the next News and Comment number (see ARB 148: 7-8).

Bablet, J.P., and Cayet, O., eds., 1972. Le monde vivant des atolls. Pub. Soc. Océanistes no. 28: 1-148. Illustrated guide to atoll natural history based on the Tuamotus. To be reviewed.

Bakus, G. J. 1969. Some effects of sedimentation on benthic invertebrates of atoll lagoons. Mem. Simp. Intern. Lagunas Costeras. UNAM-UNESCO 1967, Mexico 503-504. Abstract. Mentions experiments on sediment deposition on sponges and ascidians in Fanning Island lagoon. Concludes that sedimentation plays an important role in determining which species survive, but that most species were affected adversely.

Barthel, K.W., Janicke, V., and Schairer, G., 1971. Studies on the coral reef complex of Laisacker near Neuburg a.D (Lower Tithonian, Bavaria)., N. Jahrb. Geol. Paläont. Mohatsheft 1971 (1): 4-23. This is a descriptive account of an upper Jurassic reef of corals and mollusks, with sediment-trapping algae, and showing effects of what are probably clionid sponges. This reef rests on older sponge reefs.

Expédition Française sur les récifs coralliens de la Nouvelle-Calédonie, Vol. 5: 1-307, 1971, is devoted entirely to a memoir on the scleractinian corals of French Melanesia (New Caledonia to New Hebrides), by J.-P. Chevalier, beautifully illustrated with line drawings and 38 plates of photos. See ARB 148: 29, 1971.

Journal of the Marine Biological Association of India, vol. 11 (1 & 2), was issued in April, 1971 and is dedicated to Dr. Santappan Jones. It contains several papers on coral reefs and cays, corals and other marine organisms.

Caribbean Marine Biological Institute, Curaçao .... Collected Papers, 6(84-97): 1969-1971. The individual papers that seem likely to be of interest to ARB readers are listed as appropriate below, with references to the original places of publication.

Captain Cook's Florilegium. An item in The Times (London), January 17, 1972, announces the imminent appearance of this title, the book being printed by the Royal College of Art from copper plates engraved in 1780. After 200 years' delay, the plates are being used to illustrate plants collected by Joseph Banks on the *Endeavour* voyage, 1768-1771. Only 120 copies will be made. B.D.

Zinderen Bakker Sr., E.M. van, Winterbottom, J. M., and Dyer, R.A., eds. 1971. Marion & Prince Edward Islands. Cape Town, A.A. Balkema, xi, 427 pp. Marion and Prince Edward Islands are sub-Antarctic rather than tropical, but the volume is such a good example of a description and interpretation of an island ecosystem that we wish to call our readers' attention to it. It presents the results of the South African Biological and Geological Expedition, 1965-1966, to these bleak volcanoes situated southeast of Cape Town, and is an expedition report in the classic manner. The photos, alone, are worth the reader's time. F.R.F.

BRIEFLY NOTED ITEMS:

Coral Islands of the Western Indian Ocean: ARB 136, on Coral Islands of the Western Indian Ocean, included a series of tables listing the number of species of insects in various orders recorded from each island in the publications of the Percy Sladen Trust Expedition (Farquhar,

table 2; Cosmoledo, table 7; Astove, table 11; Assumption, table 14; Desroches, table 16; Remire, table 18). Since the Bulletin went to press, some additional records have been found in the literature, in papers overlooked when the Bulletin was in preparation. These records are noted below, and the papers themselves should be added to the lists of references on each of the islands.

Farquhar	Diptera	1 species	Bezzi 1923
Cosmoledo	Diptera	1	Austen 1920
Astove	Hemiptera	1	Green and Laing 1921
	Diptera	1	Austen 1920
Assumption	Hemiptera	1	Green and Laing 1921
	Diptera	1	Bezzi 1923
Desroches	Diptera	1	Austen 1920
		1	Bezzi 1923
Remire	Coleoptera	1	Fleutiaux 1922
	Thysanura	1	Carpenter 1916

The references are as follows:

Austen, E.E. 1920. The Percy Sladen Trust Expedition to the Indian Ocean in 1905, and in 1907-1909, under Mr. J. Stanley Gardiner, M.A. Diptera: Tabanidae. Bull. Ent. Res. 11: 43-45.

Bezzi, M. 1923. Diptera, Bombyliidae and Myiodaria (Coenosiinae, Muscinae, Calliphorinae, Sarcophaginae, Dexiinae, Tachininae), from the Seychelles and neighbouring islands. Parasitology 15: 75-102.

Carpenter, G.H. 1916. The Apterygota of the Seychelles. Proc. Roy. Irish Acad. B, 33: 1-70.

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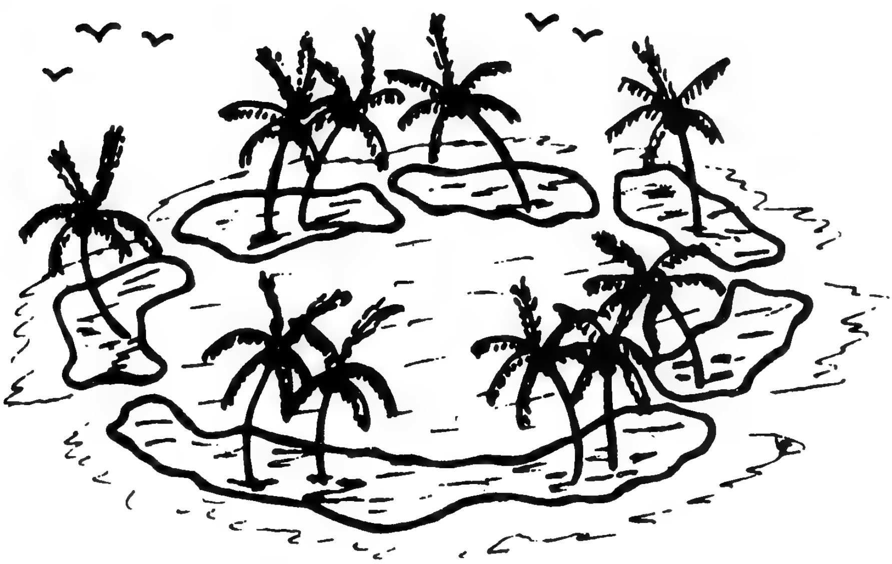

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ATOLL RESEARCH BULLETIN
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THE NATURAL HISTORY OF GARDNER PINNACLES, NORTHWESTERN HAWAIIAN ISLANDS

by Roger B. Clapp

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THE NATURAL HISTORY OF GARDNER PINNACLES, NORTHWESTERN HAWAIIAN ISLANDS[1]

by Roger B. Clapp [2]

INTRODUCTION

Gardner Pinnacles, located at 25°00'N, 167°55'W, (Figure 1) consists of two small volcanic rocks situated in the middle of the Northwestern Hawaiian Islands. Its nearest neighbors are the islands of French Frigate Shoals, 117 nautical miles to the southwest and Laysan Island, 204 nautical miles to the east-northeast. Barren, of no commercial value, and difficult to land on, these pinnacles are on the least visited islands of the chain.

Prior to recent investigations, almost all that was known of the biology of the Pinnacles was based on work done by the Tanager Expedition in 1923. Except for an aerial survey of the albatross population in 1957, no further biological work was done until 1963 when the Smithsonian Institution's Pacific Ocean Biological Survey Program (POBSP) undertook extensive surveys of the islands of the Central Pacific. During the study period (1963-1969) Gardner Pinnacles was visited twice by the POBSP and twice by personnel from the Bureau of Sport Fisheries and Wildlife. The latter visits were part of regular inspection patrols of the Hawaiian Islands National Wildlife Refuge of which Gardner Pinnacles is a part. Observations made on these four visits and the largely unpublished data obtained by Alexander Wetmore during the 1923 Tanager Expedition are the source of most new biological information presented in this report.

My purposes in preparing this report, one of a series on the islands and atolls of the Northwestern Hawaiian Islands, are several.

One aim is to present hitherto unreported observations on the vertebrate fauna and vascular flora, and to report the current status of these groups. These data are compared with previous information and, where possible, historical changes are indicated.

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2/ Present address: Department of Zoology, University of Maryland, College Park, Maryland 20742.

Another aim is to present a history of the islands that reports in detail biological work conducted there.

Much of the information on the biology of the Northwestern Hawaiian Islands is in unpublished manuscripts or is widely scattered throughout the literature. No single publication gives a concise summary of information on Gardner Pinnacles. Hopefully, this report will enable future workers quickly to assess the value of new data in various disciplines and will indicate areas of study that are still poorly known or are as yet unstudied.

I also hope that this report will stimulate further work on the biota of the island, particularly studies of a more quantitative nature than has been possible previously.

HISTORY OF GARDNER PINNACLES

All authorities on the discovery of the Northwestern Hawaiian Islands (e.g., Bryan, 1942; Stackpole, 1953; Sharp, 1960) agree that Gardner Pinnacles were discovered and named (as Gardner Island) by Captain Joseph Allen of the Nantucket whaler Maro. The Maro on its previous (and first) voyage to the Pacific had been the first American whaler to cross the mid-Pacific and had on that voyage the honor of being the co-discoverer of the famous Japanese whaling grounds. On this, its second voyage, the owners had given Allen specific orders to sail northwest from the Sandwich [Hawaiian] Islands.

On June 2, 1820, Allen found "a new island or rock not laid down on any of our charts -- Lat. 25° -3'North, and by a good lunar we found the Longitude when within 3 miles of the land to be 167° -40' West -- judge it to be 150 feet high,1/ about 1 mile in circumference. It has two detached humps...We call it Gardner's Island" (Stackpole, 1953: 269).

Gardner was sighted in 1826 by Lieutenant Hiram Paulding of the U.S. Schooner Dolphin. He reported his observations as follows:

> "At three, P.M., on the fourth of January, a rock was reported from the mast-head, eight leagues from us. It proved to be Ballard's Island, as it is called. At eight on the following morning, we passed within two hundred yards of it. It is about two or three hundred yards in circumference, and rises two hundred feet from the sea. On one side it has a considerable inclination, where seals had crawled up, and several were basking in the sun, almost to the very top. Large flocks of birds were perched on its ragged sides, or wending their flight around it. Not the least sign of vegetation was any where to be seen. Near its base, was a small rock,

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1/ Bryan (1942: 180) indicated that Allen had reported that the Pinnacles were 900 feet high. The height quoted in Stackpole (above) agrees with the original sources.

from ten to twenty feet above the water level. Ballard's Rock rises in three equi-distant peaks, the centre of which is the highest, and all of them, to the very base, are white with bird-lime. A high surf breaks all around it. Our observations placed it in north latitude, twenty-five degrees two minutes; west longitude, one hundred and sixty-seven degrees fifty minutes." (Paulding, 1831: 191-192).

The first recorded landing on the island occurred in March 1828 when crew members of the Russian vessel Moller, under the command of Captain Stanikowitch, went ashore. During this visit the ship's surgeon, C. Isenbeck, made observations of the avifauna which were later summarized by F.H. von Kittlitz (1834). Kittlitz's account was later translated and reprinted by Rothschild (1893-1900). Isenbeck reported the presence of at least 8 different species of birds but his identifications of some birds are clearly inaccurate.

No subsequent landings on the Pinnacles are known to have occurred until 1923. However, during this more than 90 year period, the island was observed from offshore on a number of occasions. In early 1857 Captain John Paty, who had been commissioned to visit the Northwestern Hawaiian Islands and determine the worth of their guano deposits, sailed by the island on a schooner Manuokawai. He reported that the island was 607 miles W-NW from Honolulu and that it was "merely two almost inaccessible rocks, 200 feet high, extending north and south about one-sixth of a mile. A bank extends off to the southwest some 15 or 20 miles. The bottom seemed to be covered with detached rocks, with sandy spaces between; I had 17 fathoms of water 10 miles south of the island." (Paty in Bryan, 1942: 180).

Two years later, on 10 January 1859, Lieut. John M. Brooke, commanding the U.S.S. Fenimore Cooper, visited the island and determined its position.

On 9 June 1891 Gardner was visited by the Kaalokai which was transporting members of the Rothschild Expedition to different islands of the Hawaiian Chain. The field party had intended to land at all islands of the Chain but had already failed to do so at Nihoa and Necker Islands, and could not land on Gardner Pinnacles because of rough seas (Palmer in Rothschild, 1893-1900: ix; Munro, 1941: 34-35). Palmer and Munro, members of the field party, did make a few bird observations.

On 3 February 1909, Gardner Pinnacles was included in the Hawaiian Islands Bird Reservation (Bryan, 1942: 182) as a result of Executive Order 1019 by Theodore Roosevelt. At that time the refuge was under the jurisdiction of the U.S. Bureau of Biological Survey, but it is now administered by the Biological Survey's successor, the Bureau of Sport Fisheries and Wildlife.

On 25 July 1940, Franklin D. Roosevelt's Presidential Proclamation 2416 changed the name of the Reservation to the Hawaiian Islands National Wildlife Refuge. Gardner, today, is still part of the

refuge and was given added protection in 1967 when it was designated a natural area within the refuge system by the Bureau of Sport Fisheries and Wildlife. Entry is by permit only and is limited to scientists on research programs.

The first significant biological survey of Gardner Pinnacles was made by the Tanager Expedition in May 1923. This expedition, which surveyed all the Northwestern Hawaiian Islands, was a cooperative venture organized and staffed by the U.S. Biological Survey and the Bernice P. Bishop Museum. Logistic support was provided by the U.S. Navy in the form of a 1,000-ton minesweeper, U.S.S. Tanager.

The ship arrived at the island on the evening of 21 May but did not land a field party until the following morning. At this time eight persons went ashore and remained on the island until about noon. These were Alexander Wetmore, leader of the field party, Stanley C. Ball, John Baker, Theodore Dranga, Eric L. Schlemmer, Ditlev Thaanum, Gerrit P. Wilder, and a Dr. Wilson.

Despite their short stay on the island, they obtained a wide variety of specimens. Thaanum and Dranga collected marine invertebrates; Baker and others caught fish; Wilder collected some algae and a specimen of the only vascular plant present; and Wetmore and Schlemmer collected some 22 bird specimens. Geological observations and collections of arthropods were made by Ball.

Many of the observations and collections were subsequently reported. Ball's geological observations were reported by Palmer (1927) and comments on the nature of the rocks were made by Washington and Keyes (1926). Fish were reported by Fowler and Ball (1925), various insects by Bryan et al. (1926), vascular plants by Christophersen and Caum (1931) and echinoderms and crustacea by Edmondson et al. (1925).

The only bird observations that were recorded, however, were a few brief comments and personal communications by Wetmore (1925; in Rice and Kenyon, 1962). Nonetheless, Wetmore made detailed notes on the birds, recording 15 species of which 8 were breeding. His observations and specimens, several of which constitute the earliest valid records of occurrence or breeding, are recorded in the body of this paper.

Since the Tanager survey, four short visits have increased our knowledge of the biota; two surveys made by the POBSP (June 1963, May 1967) and two inspections conducted by the Bureau of Sport Fisheries and Wildlife (September 1966, June 1969).

On 16 June 1963 a POBSP survey team aboard the Naval vessel U.S.S. Tawakoni (ATF-114) arrived at Gardner Pinnacles. The survey team, composed of Fred C. Sibley and A. Binion Amerson, Jr., landed by whale boat at the southeastern tip of the larger island at 0800 and spent the next seven hours surveying the fauna of the island. Most effort was expended in surveying the avifauna but a small sample of some of the arthropods present (earwigs, silverfish, flies, dermestids, other beetles, ticks) was collected as well. Occurrence of ticks was later reported by Amerson (1968).

Fifteen species of birds, 11 of which were breeding, were recorded. Of ornithological note was the discovery of breeding populations of Bulwer's Petrels, Wedge-tailed Shearwaters and Brown Boobies, species previously not known to breed on Gardner Pinnacles. No bird specimens were collected but 416 individuals of 8 species were banded (Table 1).

Table 1. Birds banded on Gardner Pinnacles 16 June 1963 by POBSP personnel

Species	Adults	Immatures	Chicks	Totals
Laysan Albatross	1	--	7	8
Bulwer's Petrel	7	--	--	7
Wedge-tailed Shearwater	21	--	--	21
Red-tailed Tropicbird	20	--	--	20
Blue-faced Booby	34	16	45	95
Gray-backed Tern	--	--	99	99
Brown Noddy	--	--	152*	152
White Tern	11	--	3	14
Totals	94	16	306	416

*An undetermined number of these birds were misidentified; they were actually young Black Noddies (See page 21).

On 16 September 1966 Gardner was visited for about two hours (c. 0910-1100) by a field party that arrived on the U.S. Coast Guard Cutter Ironwood (WAGL-297). The field party was composed of Eugene Kridler and Karl W. Kenyon (Bureau of Sport Fisheries and Wildlife), Ronald L. Walker (Hawaiian Division of Fish and Game) and Sherwin Carlquist (Claremont College, Claremont, California). A few limpets and arthropods were collected but most effort was directed toward bird observation. Fourteen species of which 7 were breeding were observed. The presence of Golden Plovers was recorded for the first time.

POBSP personnel surveyed Gardner Pinnacles for three hours (0830-1130) on 26 May 1967. The field party, which had been transported by three Navy tugs, included Robert L. DeLong, David L. Burckhalter, Dennis L. Stadel, F. Christian Thompson, and Robert Tuxson. Fourteen species of birds of which 11 were breeding were recorded. One species, the Blue-gray Noddy, was recorded breeding for the first time. No birds were banded but four returns (2 from Blue-faced Boobies, 1 from a Red-tailed Tropicbird, and 1 from a White Tern) and one recovery (of a Blue-faced Booby) were obtained.

On 1 June 1969 the island was visited from the University of Hawaii vessel Mahi by a field party led by David L. Olsen of the Bureau of Sport Fisheries and Wildlife. Olsen and two university scientists, James McVay and Thomas Clark, spent about four hours (c. 0750-1140) on the island and in surrounding waters. Eight species of birds were noted; five of these were found breeding.

Observations of the birds of Gardner Pinnacles have been made in recent years on a number of other occasions, either by aerial survey (December, 1957) or from offshore (June 1962; March, 1964, 1966, 1967). Few of these observations added anything of significance to our knowledge of the avifauna. Those that did are included in the species accounts.

DESCRIPTION

The two islands of Gardner Pinnacles are the westernmost volcanic islands in the Hawaiian area and stand on the northeastern part of a bank 20 by 50 miles in extent and with depths of from 9 to about 40 fathoms (Gr. Brit., Hydrographic Off., 1946: 299).

The smaller, more northwestern of the two islands is about 250 feet long and 100 feet wide and rises to about 100 feet at its peak (Fig. 2). The larger island, about 150 feet to the southeast, is about 700 feet long, 500 feet wide and rises to two distinct peaks (Palmer, 1927: 32; Bryan, 1939: 15). The larger of these peaks was formerly about 170 feet high but blasting away of the top of the peak by military personnel reduced its height somewhat. This was done in March 1961 to provide sites for first order astronomic and HIRAN stations (Roach, ms.) Between them the two islets have an area of about 3 acres (Freeman, 1951: 330). Between these two islets is a small rock that rises but a few feet above sea level (Palmer, op, cit.).

The rocks are liberally coated with guano, which from a distance gives them a snowcapped appearance. The cliffs are steep, but, once a landing has been affected, one can walk around the base of the larger island and to both peaks (Figs. 3-6).

GEOLOGY

Gardner Pinnacles is one of the several Northwestern Hawaiian Islands composed solely of volcanic rock. The Pinnacles, like other volcanic islands of the chain, stand on an extensive submerged platform that suggests that they are the eroded remnants of a formerly much larger volcanic island. Palmer (1927: 33) suggested that the area of the island had originally been about 80 square miles intermediate in size between Lanai and Kahoolawe. Gardner Pinnacles are believed to be intermediate in age between the older, more northwesterly Leeward islands and the younger Main Hawaiian islands (Bryan, 1954: 7-8).

Palmer (op. cit.) stated that all exposed rocks are basalt, most of which originated from flowing lava. Most of the rock is a "fine grained, very dark gray or nearly black basalt, with few if any vesicles, and with a few small phenocrysts of olivine." A detailed petrographic description of a rock specimen was given by Washington and Keyes (1926: 349) as follows: "the rock is dark gray, very dense, aphanitic and aphyric, with some very small vesicles filled with calcite." The rock was much decomposed and was "very fine grained,

containing many granules of augite with smaller ones of magnetite, which lie in a colorless base, of rather high refractive index, that Dr. Bowen thinks is probably prehnite. No unaltered feldspar, or at least very little, is present, and no olivine is visible."

BOTANY

The only vascular plants that grow on Gardner are some small patches of a *Portulaca* found in various locations on the slopes. Bryan (in Bryan *et al*., 1926) reported that these patches of plants were *Sesuvium* but his comment is evidently a *lapsus calami*. These plants were recorded by the Tanager Expedition in May 1923 and on the recent surveys of June 1963, September 1966, and May 1967. The only specimen that has been collected was one collected by Gerrit P. Wilder on 22 May 1923.

Regarding this specimen, Christophersen and Caum (1931: 8) wrote that it "had disappeared from the general collection of the Tanager Expedition" leaving the duplicate field label as the only record. Recently, the long missing specimen (Wilder No. 10) returned to the Herbarium of the B.P. Bishop Museum from the Netherlands. In August 1969, R. Geesink identified the specimen as *Portulaca lutea* Sol. (D.L. Herbst, pers. corres.), a plant of widespread distribution in the central Pacific area.

Spiney seeds of *Tribulus cistoides* L., apparently brought to the island on the feet or plumage of seabirds, were also found in 1923 (Wetmore, 1925: 82), but the plant is not known to grow on Gardner.

VERTEBRATE FAUNA

Reptiles and Mammals

POBSP personnel saw a single Green Turtle (*Chelonia mydas*) swimming offshore 16 June 1963 and another individual, about two feet long, was seen offshore on 16 September 1966 (Kridler, ms., b.). This turtle, not previously recorded from Gardner Pinnacles, does not breed there since the pinnacles afford no suitable nesting habitat. Presumably the turtles seen in 1963 and 1966 were wandering individuals from populations on other of the Northwestern Hawaiian Islands.

The only mammal occurring on Gardner is the Hawaiian Monk Seal which was first noted in 1826 by Hiram Paulding (1831: 191). These seals were not seen there again for over 130 years. This absence of records probably stems from a paucity of observations of the Pinnacles rather than an absence of seals since these mammals have been seen quite regularly during recent visits to the islands.

On the first POBSP survey (16 June 1963) the field party saw two seals sunning themselves on the smaller of the two islands. On 16 September 1966, Kridler's field party saw five seals, four resting on the smaller island, another swimming nearby. Six were seen on the

second POBSP survey (26 May 1967), again on the smaller island. These seals were hauled out on a ledge about 2 feet above the water surface which was reached by riding the swells. On 1 June 1969 Olsen saw six hauled up on the small island. No evidence that breeding occurs on this island has been found.

Birds

Composition of the Avifauna

At present 19 species of birds have been reported from Gardner Pinnacles, not including two species (Christmas Shearwater, Harcourt's Storm Petrel) recorded only from offshore (Table 2). The record for one (White-tailed Tropicbird) of the 19 species recorded from the island is of doubtful validity with the result that only 18 species are certainly known to have occurred there.

Twelve species are known to breed on Gardner Pinnacles but five (Laysan Albatross, Bulwer's Petrel, Wedge-tailed Shearwater, Brown Booby, Blue-gray Noddy) are uncommon with none having breeding populations much exceeding several dozen birds.

Two other species (Red-footed Booby, Great Frigatebird) that breed commonly on other Northwestern Hawaiian Islands occur on Gardner only as visitors. The reason that neither species breeds there may well be that the island lacks sufficient vegetation to permit either to build nests.

Only a few species of shorebirds and vagrants are known from Gardner, partly because so few observations have been made, partly because the Pinnacles lack habitat that would attract shorebirds and the kinds of vagrants most commonly occurring in the Northwestern Hawaiian Islands (ducks and gulls).

Historical Changes in the Size of Populations

Few of the breeding populations appear to have changed much in the last 45 years. Gray-backed Terns, Sooty Terns, and particularly Brown Noddies apparently have increased significantly in numbers since 1923. The number of Blue-faced Boobies, on the other hand, evidently has decreased substantially.

Recent estimates are somewhat larger than in 1923 for three other breeding species (Layson Albatross, Red-tailed Tropicbird, Black Noddy) and somewhat smaller for another (White Tern) but the differences in the estimates from the two periods are not sufficiently large so that any real change is clearly indicated.

Four other species (Bulwer's Petrel, Wedge-tailed Shearwater, Brown Booby, Blue-gray Noddy) were not known to breed on Gardner until very recently but it is likely that they have bred there in small numbers for many years.

Table 2. The avifauna of Gardner Pinnacles

	Species	Current Status	Maximum Population Estimate	Date when Maximum Estimate Recorded
	RESIDENT SEABIRDS OF THE NORTH CENTRAL PACIFIC			
	Laysan Albatross	Uncommon breeder	14	June 1963
	Bulwer's Petrel	Uncommon breeder	25	June 1963
+	Wedge-tailed Shearwater	Uncommon breeder	c. 25	June 1963
	Red-tailed Tropicbird	Common breeder	100	June 1963
	Blue-faced Booby	Common breeder	800	May 1923
	Brown Booby	Uncommon breeder	20	June 1969
	Red-footed Booby	Occasional visitor	12	May 1923
	Great Frigatebird	Common visitor	250	May 1923
	Gray-backed Tern	Abundant breeder	4,000	May 1967
*+	Sooty Tern	Common breeder	500-1,000	June 1963
+	Blue-gray Noddy	Uncommon breeder	c. 20	May 1967
	Brown Noddy	Abundant breeder	5,000	June 1963
	Black Noddy	Common breeder	400	May 1967
+	White Tern	Common breeder	300-400	May 1923
	SHOREBIRDS			
*	Golden Plover		2	September 1966
	Wandering Tattler		1-2	May 1923,1967,1969
*	Ruddy Turnstone		15	May 1923
	VAGRANTS			
*	Gull sp.		1	March 1967
	HYPOTHETICAL AND RECORDED ONLY OFFSHORE			
	Harcourt's Storm Petrel	Hypothetical offshore visitor	--	--
	White-tailed Tropicbird	Hypothetical visitor	--	--
	Christmas Shearwater	Offshore visitor	--	--

+Breeding not reported previously
*Not previously reported from Gardner Pinnacles

Banding

Only four of the 416 birds banded by the POBSP (Table 1) were recaptured at Garnder Pinnacles by the POBSP; a very few were recaptured in other areas. Returns, where significant, and movements are given in the various Species Accounts.

Specimens

The only bird specimens collected on Gardner Pinnacles are those obtained by Wetmore on 22 May 1923. All are now located in the National Museum of Natural History. These specimens are listed in Table 3.

Table 3. Bird specimens collected by Wetmore on Gardner Pinnacles

Species	No. of Specimens Collected	Sex and Museum Numbers of Specimens
Wedge-tailed Shearwater (*Puffinus pacificus*)	1	♂, USNM 300726
Red-tailed Tropicbird (*Phaethon rubricauda*)	3	♂, USNM 300989; ♀, USNM 300998; juv. ♂, USNM 300990
Blue-faced Booby (*Sula dactylatra*)	2	♂, USNM 300946; ♀, USNM 300945
Great Frigatebird (*Fregata minor*)	1	♀, USNM 465204
Ruddy Turnstone (*Arenaria interpres*)	2	♂♂, USNM 367383, 393507
Gray-backed Tern (*Sterna lunata*)	3	♂♂, USNM 300649, 300650; ♀, 300651
Sooty Tern (*Sterna fuscata*)	3	♂, USNM 300358; ♀♀, USNM 300539, 300540
Blue-gray Noddy (*Procelsterna cerulea*)	3	♂, USNM 300387; ♀♀, USNM 300428, 300429
Brown Noddy (*Anous stolidus*)	1	♀, USNM 300521
Black Noddy (*Anous tenuirostris*)	2	♂, USNM 300458; ♀, USNM 300454
White Tern (*Gygis alba*)	2	♂, USNM 300415; ♀, USNM 300416
	23	

Species Accounts

In the following species accounts, **brackets** around accounts indicate that occurrence on the island is not adequately substantiated.

LAYSAN ALBATROSS *Diomedea immutabilis*

Although Rice and Kenyon (1962: 376) state that they found no published references to albatross on Gardner Pinnacles other than a statement that Laysan Albatrosses breed there (A.O.U., 1957: 9), there are at least two earlier published references, one of which (Bryan, 1901: 266) probably derives from the other (Rothschild, 1898-1900: iii). Rothschild's translation of the account of Isenbeck's visit in March 1828 stated that an albatross "white, with flesh-coloured

bill, varying with white; grey and black wings...[was] plentiful on Gardner, where they seemed to live on the highest parts." This description best fits the Laysan Albatross but other observations and descriptions in this account are often inaccurate or incomplete. Possibly Isenbeck's observations were of Blue-faced Boobies. Recent observations of the birds of Gardner Pinnacles indicate that these boobies are abundant near the tops of the larger pinnacle, while albatrosses are scarce (Table 4).

Table 4. Recent observations of Laysan Albatrosses on Gardner Pinnacles

Date of Survey	Estimated Adult Population	Remarks
22 May 1923	4	Two nearly grown young found on the northwestern slope in small depressions in the rock about 100 feet above the water (Wetmore, ms.)
28 December 1957	3	Two seen on pinnacle, one flying nearby, during aerial survey by Rice and Kenyon (1962: 376). Nesting could not be ascertained but Rice and Kenyon believed that a pair might be breeding there.
16 June 1963	14	Seven large chicks banded on the higher slopes of the pinnacles (POBSP).
26 May 1967	2	One large chick found (POBSP).
1 June 1969	0	None present (Kridler, *pers. comm.*)

BULWER'S PETREL *Bulweria bulwerii*

There are only two certain records, both recent, of Bulwer's Petrels from Gardner Pinnacles, but an earlier observation, interpreted by Rothschild (1893-1900: v) as a record of the Christmas Shearwater (which see), may have been of this species. On 16 June 1963 POBSP personnel found ten nests, all containing eggs, and estimated an adult population of about 25 birds (Clapp and Woodward, 1968: 7). On 16 September 1966, Kridler (ms., b) saw an adult in a crevice and found three young, all nearly fledged. These observations suggest that egg-laying occurs in May or June and that the breeding season is completed sometime in September which agrees well with the nesting cycle proposed by Richardson (1957: 18) for other breeding stations in the Northwestern Hawaiian Islands.

WEDGE-TAILED SHEARWATER *Puffinus pacificus*

Wedge-tailed Shearwaters were reported from the Pinnacles by Rothschild on the basis of observations made in March 1828 by Isenbeck. In this instance, as in several others, the description was not detailed enough for reliable identification, and re-examination of it suggests that Rothschild's identification may have been incorrect.

The bird that Rothschild (1893-1900: v) identified as a Wedge-tailed Shearwater was described as "[a] Petrel, a little larger [than 9 inches long], breast, abdomen, and neck white; upper surface mixed white and brown; the forked tail only moderately emarginate." This description could apply as easily to a young Gray-backed Tern, which has a speckled back, white underparts, and a forked tail, as it could to a Wedge-tailed Shearwater, which has a cuneate tail and whose upper-parts show little white and only on new feathers. Isenbeck did not distinguish between terns and petrels in his vernacular identifications. Another bird whose description clearly identifies it as an adult Gray-backed Tern (and identified as such by Rothschild) was referred to as a "Petrel" by Isenbeck.

Recent observations confirm that Wedge-tailed Shearwaters occur and breed on Gardner Pinnacles but suggest that the population is small. Wetmore (ms.) found a single bird deep in a crevice on the western face of the island, but his companion, Stanley C. Ball, saw two others. Wetmore's notes do not indicate that he found any nesting birds.

On 16 June 1963 POBSP personnel discovered nesting Wedge-tailed Shearwaters. Twenty-one adult shearwaters were taken from rocky crevices and banded. Stage of incubation was not checked but the presence of only eggs in mid-June suggests that most laying occurs about June in this colony as in other colonies in the Northwestern Hawaiian Islands (see Richardson, 1957: 17).

Kridler (ms., b) found four downy young in mid-September 1966. This indicates that the breeding season would not have been completed for at least another month.

In late May 1967, POBSP personnel again recorded these shear-waters on Gardner Pinnacles. Several birds flushed from holes in the rocks, but the single cavity examined was empty. About 20 shearwaters were believed present but nocturnal populations may have been larger. The total breeding population, however, is certainly not very large, and is probably comprised of less than 100 birds.

[CHRISTMAS SHEARWATEP *Puffinus nativitatus*

In March 1828 Isenbeck saw a petrel on Gardner Pinnacles that he described as "about 9 inches long; all over deep chestnut-brown, with blackish bill and feet and a cuneate tail" (Isenbeck *in* Rothschild, 1893-1900: v). Rothschild believed that this description referred to the Christmas Shearwater and therefore recorded that species from Gardner Pinnacles.

This description fits Bulwer's Petrel better than it does the Christmas Shearwater, and, since in at least one other instance Isenbeck identified a tern as a petrel (Rothschild, 1893-1900: v), could conceivably have referred to an immature Brown Noddy.

Rothschild's interpretation of Isenbeck's observation is the only record of Christmas Shearwaters on Gardner Pinnacles. Neither Wetmore

nor any subsequent observer found any of these shearwaters on the island. The only recent record of their occurrence in the vicinity of Gardner is Wetmore's observation (ms.) of one or two flying around the _Tanager_ offshore.]

[HARCOURT'S STORM PETREL _Oceanodroma castro_

Peterson (1961: 318) gives the range of Harcourt's Storm Petrel in the Hawaiian Islands as from Gardner Pinnacles to the main islands. His inclusion of Gardner Pinnacles apparently has as its basis Munro's observation (1944: 29) that he and Palmer had seen a white-rumped storm petrel on 10 June 1891, the day before their ship, the _Kaalokai_, reached Gardner Island. Munro (and apparently Peterson after him) assumed that a white-rumped storm petrel could only be _Oceanodroma castro_. Recent observations and collections in the Northwestern and main Hawaiian Islands indicate that Leach's Storm Petrel (_Oceanodroma leucorhoa_) occurs regularly at sea in the area (Bryan, 1965: 79; Throp, 1967: 83; Clapp and Woodward, 1968: 9-10) and suggest that many early sight records of _castro_ were actually of _O. leucorhoa_. In any case there is no evidence that Harcourt's Storm Petrel occurs or has occurred on Gardner Pinnacles.]

RED-TAILED TROPICBIRD _Phaethon rubricauda_

Red-tailed Tropicbirds are stated to occur on Gardner Pinnacles in both the A.O.U. Checklist (A.O.U., 1957: 28) and Richardson (1957: 19). These records (for which no further details are given) probably are based on the otherwise largely unpublished observations of Alexander Wetmore.

The only other published record that I have found is Henry Palmer's comment (_in_ Rothschild, 1893-1900: ix) that he had seen "the Tropicbird" (presumably the Red-tailed Tropicbird) when he passed Gardner Pinnacles in June 1891.

Other observations of this species on Gardner Pinnacles are presented in Table 5.

R.R. Fleet (_pers. comm._) states that the incubation period of Red-tailed Tropicbirds is about 43 days. Using this datum I can interpolate from the nesting data given below and arrive at crude estimates of peak egg laying periods in each year. A peak of egg laying evidently occurred in April 1923 and another peak occurred in May or June 1963. The 1967 observations may indicate an April or May peak of laying. The breeding cycles in both 1963 and 1967 (barring disruption of nesting cycles through nest failure) evidently began later than in 1923.

A Red-tailed Tropicbird banded as a nestling, 16 June 1963, was found incubating an egg on 26 May 1967, demonstrating that age of first breeding may be as little as four years. (Unpublished POBSP data from other Northwestern Hawaiian Islands indicate that age of first breeding may be as little as three years.)

Table 5. Recent observations of Red-tailed Tropicbirds on Gardner Pinnacles

Date of Survey	Estimated Population	Remarks
22 May 1923	c. 30*	One or two birds with eggs found; others seen with young from four days to a week old (Wetmore, ms.)
16 June 1963	100	Many nesting in crevices and holes and under rocky overhangs. All nests examined contained eggs (POBSP).
16 September 1966	?	Four adults seen. Two large young with nearly-complete juvenal plumage were found two-thirds of the way up the main pinnacle (Kridler, ms., b).
26 May 1967	35	16 of 17 nests found contained eggs; the other contained a chick about a week old. Nests in caves or under rock piles. Considerable egg mortality caused by eggs being displaced from nest sites (POBSP).
1 June 1969	24	Seen flying about the island. No nests found (Olsen, ms.)

*Estimate is of the number of breeding birds.

[WHITE-TAILED TROPICBIRD *Phaethon lepturus*

Only a single observation suggests that the White-tailed Tropicbird could be included in the avifauna of Gardner Pinnacles. In March 1828 Isenbeck (Rothschild, 1893-1900: iv) saw a single "*Phaethon* (an *candidus*?) [sic] with white, somewhat broad tail-feathers" flying high in the air near Gardner Pinnacles. If this observation was indeed of a White-tailed Tropicbird, the bird may have been a wanderer from the populations breeding in the main Hawaiian Islands.]

BLUE-FACED BOOBY *Sula dactylatra*

All data on Blue-faced Boobies on Gardner Pinnacles, aside from a statement that it breeds there (Richardson, 1957: 20) are observations made by Wetmore on 22 May 1923, and those made by the few subsequent observers (Table 6).

These data indicate a marked decrease in the number of breeding birds between 1923 and 1963. This decrease may have been caused by the demolition of the top of the main pinnacle by military personnel. Both Wetmore and the POBSP observers noted that these boobies nested primarily on the upper third of the larger pinnacle. In May 1967, in fact, the area of greatest nest density was the area leveled by the blasting (Fig. 7).

Table 6. Observations of Blue-faced Boobies on Gardner Pinnacles

Date of Survey	Estimated Population	Remarks
22 May 1923	800*	Nesting varied from nest-site selection to well-grown young. Some post-fledging young also seen (Wetmore, ms.).
16 June 1963	150	72 nests and recently fledged young counted, including 3 nests with eggs (4 percent of the breeding population), 53 nests with small to large young (74 percent) and 16 immature birds (22 percent) (POBSP).
16 September 1966	80	15 immatures, all capable of flight, and one small downy young (about a week old) counted (Kridler, ms., b.).
26 May 1967	250	An estimated 120 breeding pairs were present, 15 percent with nests with eggs, 15 percent with naked and small downy young, 60 percent with medium-sized to large downy young, and 10 percent with immatures (POBSP).
1 June 1969	75	Most with half-grown young (Olsen, ms.).

*Estimate is of the number of breeding birds.

By interpolation from known incubation and fledging periods (together about 170 days [Dorward, 1962]), some statements may be made about the length of the breeding season, and, in the case of POBSP observations, when most egg-laying occurred. The presence of well-grown young in May 1923 indicates that some birds must have been nesting in the preceding March or even earlier. The POBSP data suggest that in 1963 most egg-laying occurred in March-April and that in 1967 most egg-laying occurred in a roughly similar period. The presence of recently hatched young in June 1963 and May 1967 and of downy young in September 1966 indicates that an occasional pair of Blue-faced Boobies may be found breeding in almost any month of the year. It seems likely that relatively few nest during the late fall and winter months and that most nest during spring and summer.

In only one instance has a club, a tightly packed aggregation of roosting birds, been seen on Gardner Pinnacles. Eight birds were roosting together on top of the larger pinnacle when the POBSP survey team arrived at the island at 0830, 26 May 1967. It is likely that larger aggregations roost on the island at night.

Two Blue-faced Boobies of the 95 banded by the POBSP were subsequently recaptured on other islands. One banded as an adult was recaptured 18 September 1964 on Laysan Island, 204 nautical miles to

the west-northwest; the other banded as a nestling was recaptured 28 February 1965 (as an adult) on Sand Island, Johnston Atoll, 495 nautical miles to the south-southwest.

BROWN BOOBY *Sula leucogaster*

The Brown Booby is the least common breeding bird on Gardner Pinnacles and apparently has been uncommon there for at least the last 45 years. A single Brown Booby was seen on the western rock by members of the Tanager party in May 1923 (Wetmore, ms.). POBSP survey teams saw few during their two surveys. On 16 June 1963 one was found incubating two eggs (Clapp and Woodward, 1968: 12) and on 26 May 1967 three adults and a nestling were seen. Kridler (ms., b.) saw four adults and a flying immature on 16 September 1966, and on 1 June 1969 Olsen (ms.) recorded 20, most of which had young.

RED-FOOTED BOOBY *Sula sula*

Red-footed Boobies apparently occur on Gardner Pinnacles only as visitors. On 22 May 1923 Wetmore (ms.) saw about a dozen flying about the island at daybreak but found none roosting on the island. POBSP personnel found a single immature or subadult bird roosting on the island on 16 June 1963 (Clapp and Woodward, 1968: 11) and Kridler (ms., a.) saw two flying above the pinnacles in March 1966. Judging from nocturnal observations on other of the leeward islands, it is probable that larger numbers may be found roosting there at night.

GREAT FRIGATEBIRD *Fregata minor*

Great Frigatebirds occur at Gardner Pinnacles only as visitors. They were first recorded in March 1828 by Isenbeck. Kittlitz (*in* Rothschild, 1893-1900: iii-iv) believed that the immature and sub-adult-plumaged birds that were seen comprised a different species from what are now known to be adults. He reported that Isenbeck had seen a single "*Tachypetes aquilus*" (= adult Great Frigatebird) and that the other species (= immature and sub-adult Great Frigatebirds) was common.

All recent visitors to the island have seen Great Frigatebirds flying over the pinnacles or roosting upon them but have found none nesting. Wetmore saw about 250 frigatebirds in May 1923. POBSP personnel found several hundred roosting there in June 1963 and saw about 70, some of them roosting on the outer pinnacle, in May 1967. Kridler (ms., b.) estimated that about 200 roosted on the island in September 1966.

It seems likely that the near-absence of vegetation and the concomitant reduction in nest sites, or perhaps more importantly the lack of nest materials, has prevented the colonization of Gardner Pinnacles by both this species and the Red-footed Booby.

GOLDEN PLOVER *Pluvialis dominica*

Two plovers seen by Kridler (ms., b) on 16 September 1966 constitute the only record for Gardner Pinnacles.

WANDERING TATTLER *Heteroscelus incanum*

Tattlers have been seen on the five most recent surveys on Gardner Pinnacles and are evidently the shorebird most likely to occur there. Wetmore (ms.) saw one or two of these birds running about the rock ledges near the edge of the water on 22 May 1923. POBSP personnel saw a single tattler three separate times on 16 June 1963. In one instance this bird was seen on top of the island. Kridler (ms., b.) saw another tattler 16 September 1966, POBSP personnel saw two on 26 May 1967 and Olsen (ms.) saw one on 1 June 1969.

RUDDY TURNSTONE *Arenaria interpres*

Ruddy Turnstones have been seen three times on Gardner Pinnacles. On 22 May 1923 Wetmore recorded a flock of about 15 near the water. Kridler (ms., b.) saw six on 16 September 1966 and POBSP personnel reported a single turnstone on 26 May 1967.

A turnstone that Wetmore collected had recently eaten a tern's egg.

GULL *Larus* sp.

On 15 March 1967, while passing north of Gardner Pinnacles, Kridler observed what he believed was a Glaucous-winged Gull (Hackman, *pers. corr.*), but substantive details are lacking. Isenbeck reported that "a large gull, with flesh-coloured beak [was seen] in great numbers around the top of Gardner Island" (Rothschild, 1893-1900: v). Although gulls frequently occur in the Northwestern Hawaiian Islands, they are never seen in such numbers as Isenbeck indicated. Presumably Isenbeck's observation referred to some other species, possibly the Red-footed Booby.

GRAY-BACKED TERN *Sterna lunata*

Kittlitz (*in* Rothschild, 1893-1900: v) reported a bird that Isenbeck indicated was numerous and breeding on the Pinnacles in March 1828. From Isenbeck's description, Kittlitz identified it as a "*Sterna* (?)." Rothschild (*op. cit.*) translated the description as "about 9 inches long; white, with greyish wings, back and crown; tail with two long lateral rectrices" and identified the bird as the Gray-backed Tern. Table 7 presents subsequent observations of Gray-backed Terns from survey parties that landed on Gardner.

Richardson (1957: 24) summarized available information on breeding cycles of Northwestern Hawaiian Islands birds and stated that "adults apparently arrive at breeding islands in late February or early March." He further indicated that egg-laying occurred in March or April. Although a large proportion of the 1967 population seems to have been following this regime, nearly half the population apparently laid eggs in months other than March or April. (Most of the eggs in the 400 nests with eggs probably were laid in May and some of the flying immatures probably came from eggs laid in February). Similarly, since the Gray-backed Tern incubation period is about one month, the many eggs present in June 1963 could not have been laid earlier than May although most of the young probably came from eggs laid in March or

April. The 1923 and 1969 observations, on the other hand, agree well with the breeding cycle proposed by Richardson. The data thus indicate that the peak laying periods are somewhat variable from year to year and that eggs may be laid from as early as late February through at least late May.

Two of the 99 young Gray-backed Terns banded 16 June 1963 by the POBSP were later recaptured on other islands. One was recaptured 31 August 1965 on Whale Island, French Frigate Shoals, at a distance of about 117 nautical miles to the southeast of Gardner Pinnacles. The other was stoned to death on 8 September 1963 by boys at the Mission at Kieta (6°13"S, 155°38'E) on Bougainville Island in the Territory of New Guinea. This locality is approximately 4,600 nautical miles to the southwest of Gardner Pinnacles.

Table 7. Recent observations of Gray-backed Terns on Gardner Pinnacles

Date of Survey	Population	Remarks
22 May 1923	1,400	Some terns sitting on eggs but most with young, some of these more than a week old (Wetmore, ms.).
16 June 1963	2,000	Many incubating eggs; others observed with young (POBSP).
16 September 1966	--	One immature seen flying overhead (Kridler, ms., b.). The breeding population evidently had left the island.
26 May 1967	4,000	Perhaps no less than 3,400 breeding birds present. All stages of nesting observed. Ca. 400 nests with eggs; 800 small to large downy chicks, and 500 flying immatures seen. Eggs found varied from fresh to heavily incubated (POBSP).
1 June 1969	750	Most numerous bird on island; most birds with young varying in age from recently hatched young to fledged birds. Some pipped eggs present (Olsen, ms.).

SOOTY TERN *Sterna fuscata*

Bryan and Greenway (1944: 119) indicate that the occurrence of Sooty Terns on Gardner Pinnacles is based on a sight record published by Rothschild (1893-1900). I checked this volume thoroughly but was unable to discover any mention of the occurrence of Sooty Terns on the pinnacles. That this record was in error was overlooked by Clapp and Woodward (1968). Hence, the observations given below constitute the first valid report of Sooty Terns from Gardner Pinnacles (Table 8).

Table 8. Observations of Sooty Terns on Gardner Pinnacles

Date of Survey	Size of Breeding Population	Remarks
22 May 1923	100-150	Most breeding on higher ledges with smaller numbers breeding among nesting Gray-backed Terns (Wetmore, ms.).
16 June 1963	500-1,000	Most incubating eggs but a few with chicks. A very few immatures seen flying about the island (POBSP).
16 September 1966	--	One half-grown young seen and a single adult heard (Kridler, ms., b.). Breeding season evidently completed.
26 May 1967	800	Most nesting birds with young, a few incubating eggs. Most young several weeks old but young from about a week old to near-fledging seen. About ten times as many rotten eggs as live young present (POBSP).
1 June 1969	--	A single dead bird found (Olsen, ms.).

Data presented in this table suggest that the population may have increased since 1923, and may also indicate that the peak of egg-laying varies from year to year. In 1963 the predominance of incubated eggs suggests that most eggs had been laid in the preceding May. In 1967 the predominance of chicks and rotten eggs suggest that most egg-laying occurred in April. The absence of these terns in June 1969, though unexpected, is perhaps explicable in terms of a complete nesting failure, or failure to nest, earlier in the year.

BLUE-GRAY NODDY *Procelsterna cerulea*

Blue-gray Noddies have been seen three times on Gardner Pinnacles but only the June 1963 observations were previously reported (Clapp and Woodward, 1968: 29). POBSP personnel saw 8 to 10 of these birds 16 June 1963. Most were sitting on the north side of the sheer cliffs but four were seen on the cliffs on the east side where Wetmore saw them.

Previously, on 22 May 1923, Wetmore (ms.) saw "about a dozen" Blue-gray Noddies and collected three of them.

On neither of these visits to Gardner Pinnacles was any confirmation of their breeding status obtained. On 26 May 1967, however, POBSP personnel found two eggs deposited on the exposed surface of the rocks near a nesting colony of Gray-backed Terns. On that date an estimated 20 Blue-gray Noddies were seen.

BROWN NODDY   <u>Anous stolidus</u>

Clapp and Woodward (1968: 30) first reported Brown Noddies from Gardner Pinnacles on the basis of a visit made by the POBSP in June 1963 and also reported offshore observations made in March 1967. Table 9 adds more recent POBSP observations and previously unreported observations made by other survey parties landing on the island.

Table 9. Observations of Brown Noddies on Gardner Pinnacles

Date of Survey	Estimated Population	Remarks
22 May 1923	250	Most nesting on the ledges in open colonies. Most terns were on eggs but one or two nearly grown young were observed as well (Wetmore, ms.).
16 June 1963	5,000	Many nests with eggs; about 400 nestlings present (POBSP).
16 September 1966	700-800	About 100 young from half-grown to nearly fledged were observed (Kridler, ms., b.).
26 May 1967	4,000	A census of part of the colony (487 nests and young) revealed 78 percent nests with eggs; 12 percent small downy chicks, 6 percent medium-sized downy chicks, and 4 percent with large downy chicks. Personnel estimated that 2,000 to 3,000 breeding birds were present (POBSP).
1 June 1969	500	Most had young; some almost ready to fly (Olsen, ms.).

The few available observations suggest that Gardner Brown Noddies nest primarily during spring and summer with most egg-laying usually occurring in April or May. Extrapolations from the presence of eggs and chicks in different numbers indicate that nesting takes place from at least March through October.

Some of the Brown Noddies observed by the POBSP constructed flimsy, flat nests of feathers and bits of <u>Portulaca</u>. Most, however, laid their eggs on bare rocks.

BLACK NODDY   <u>Anous tenuirostris</u>

The only previously published report of this species from Gardner Pinnacles is an account of observations made in June 1963 by the POBSP (Clapp and Woodward, 1968: 30). These and more recent observations, and observations made by Wetmore in 1923, are summarized in Table 10.

Table 10. Observations of Black Noddies on Gardner Pinnacles

Date of Survey	Estimated Population	Remarks
22 May 1923	210	About 10 nesting pairs found. Some 200 birds found roosting in flocks near the water (Wetmore, ms.).
16 June 1963	15	At least two young birds present (POBSP).
26 May 1967	400*	About 200 nests found in small colonies on rock ledges. The largest colony contained about half a dozen nests. Nests were composed of feathers, bits of *Portulaca*, and an unidentified seaweed. All stages of nesting from eggs through downy young to flying immatures were observed (POBSP).
1 June 1969	--	None seen (Kridler, *pers. comm.*).

*Estimate is of the number of breeding birds

These data suggest that Black Noddies regularly breed on Gardner. The data are too fragmentary and inconsistent from the 1963 to the 1967 survey for me to determine more of the nature of the breeding cycle than that some breeding has occurred in the months from March through at least July.

On 31 August 1965 an adult Black Noddy, misidentified as a local Brown Noddy when banded, was captured on Whale Island, French Frigate Shoals, about 110 miles southeast of Gardner Pinnacles. This bird had been banded on Gardner Pinnacles in June 1963. This error indicates that the number of breeding Black Noddies present in June 1963 was higher than reported earlier (Clapp and Woodward, 1968: 30). One of the banders states, however, that the error in numbers reported was confined to young Black Noddies and that the estimate of the number of adults seen was correct.

WHITE TERN *Gygis alba*

The only previously published record of White Terns on Gardner Pinnacles is a single sighting from offshore on 7 June 1891 (Palmer *in* Rothschild, 1893-1900: ix). To this I add a number of more recent observations (Table 11).

Interpolation from these few visits suggests that breeding occurs from at least as early as March through November or December and very likely throughout the year.

Table 11. Recent observations of White Terns on Gardner Pinnacles

Date of Survey	Estimated Population	Remarks
22 May 1923	300-400	Nesting on the rocks. A collected female contained a developing egg (Wetmore, ms.).
16 June 1963	150-200	Nesting in stages from egg to immature (POBSP).
16 September 1966	75-100	Stages of nesting observed included eggs and from newly hatched young to flying immatures (Kridler, ms., b.)
26 May 1967	150-300	Nests with eggs; small, medium, and large downy chicks and flying immatures were observed. No one stage of breeding seemed any more numerous than any other (POBSP).
1 June 1969	300	Only eggs seen, no young noted (Olsen, ms.).

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GARDNER PINNACLES

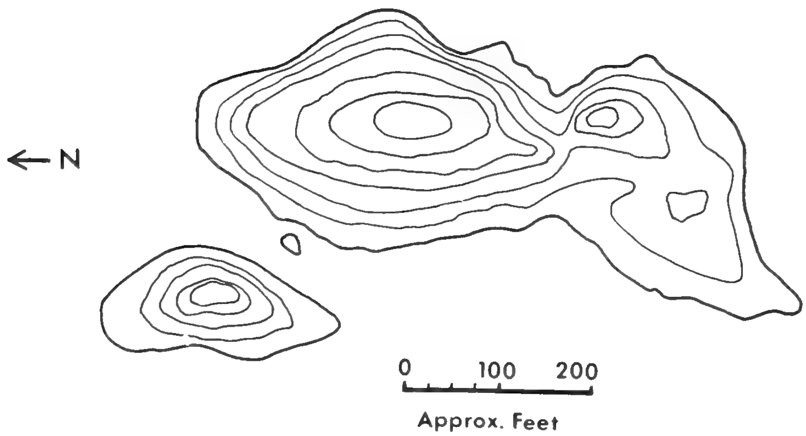

Figure 1. Map of Gardner Pinnacles. Contour interval -- 25 feet. After Palmer, 1927

Figure 2. The smaller of the two pinnacles as seen from the larger, May 1967. POBSP photograph by F.C. Thompson.

Figure 3. Gardner Pinnacles from the southeast, March 1964. POBSP photograph by A.B. Amerson, Jr.

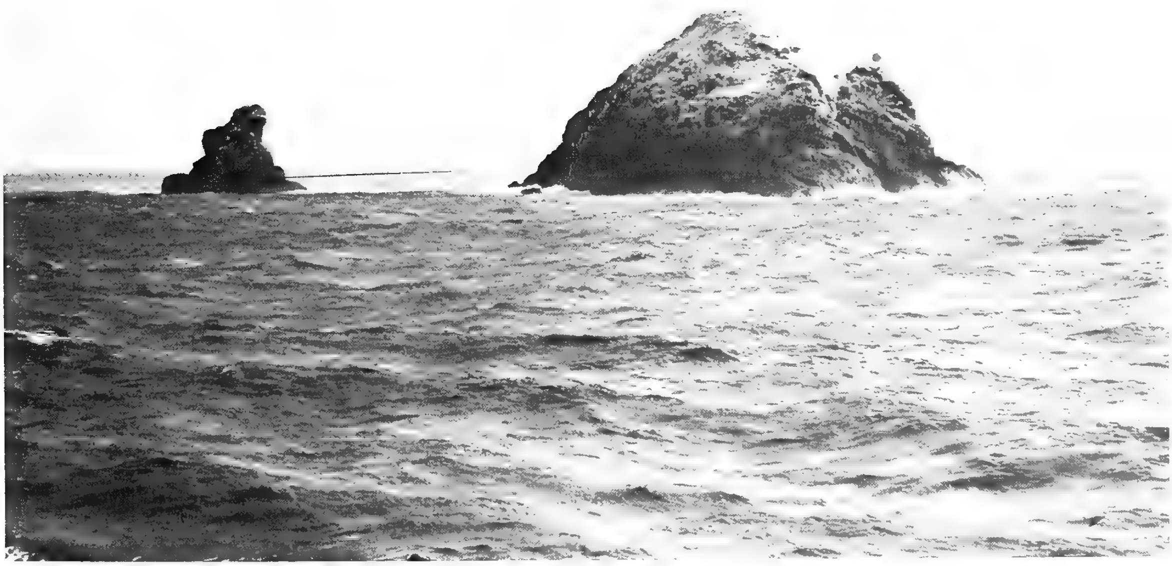

Figure 4. Gardner Pinnacles from the southwest, March 1964. POBSP photograph by A.B. Amerson, Jr.

Figure 5. Gardner Pinnacles from the north, March 1964. POBSP photograph by A. B. Amerson, Jr.

Figure 6. Looking toward the smaller peak of the larger pinnacle from the taller peak, May 1967. POBSP photograph by D. L. Burckhalter.

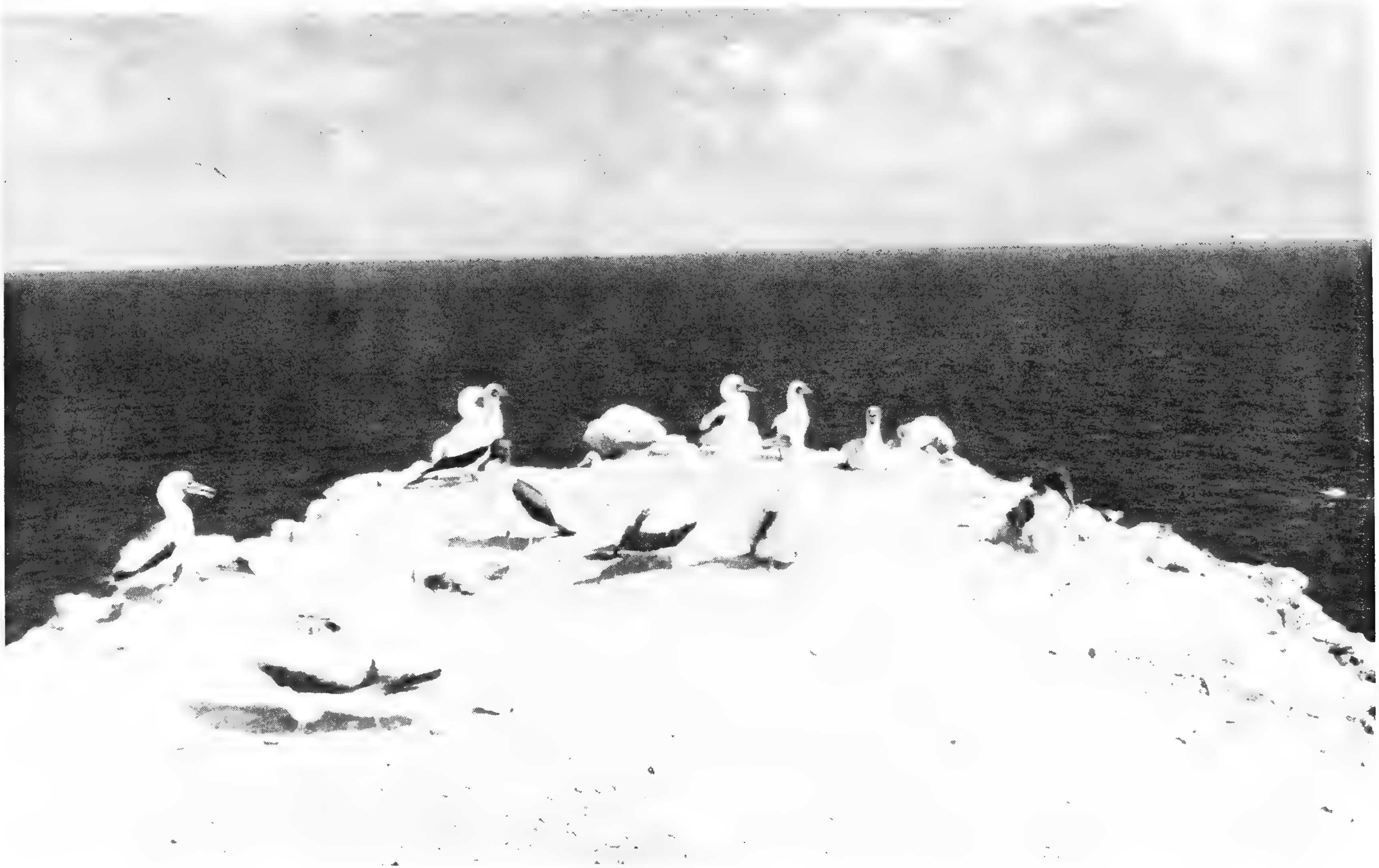

Figure 7. Nesting and young Blue-faced Boobies on the flat summit of the larger pinnacle, May 1967. POBSP photograph by D. L. Burckhalter.

ATOLL RESEARCH BULLETIN
No. 164

THE NATURAL HISTORY OF KURE ATOLL, NORTHWESTERN HAWAIIAN ISLANDS

by Paul W. Woodward

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THE NATURAL HISTORY OF KURE ATOLL,

NORTHWESTERN HAWAIIAN ISLANDS[1]

by Paul W. Woodward [2]

INTRODUCTION

Kure Atoll, located at 28°25'N and 178°10'W, is the northernmost coral atoll in the world and the westernmost land of the Northwestern Hawaiian Islands. It is approximately 1,175 nautical miles northwest of Honolulu, 2,165 nautical miles southeast of Tokyo, and 3,240 nautical miles west of Baja California. The nearest land is Sand Island, Midway Atoll, 49 nautical miles to the southeast.

Green Island, the only permanent land in the atoll, is located near the fringing reef in the southeast sector of the lagoon. Crescentric in shape with the long axis curving from north to west, it is 1.43 miles in greatest length and 0.37 miles in maximum width. Sandy beaches encircle the entire island. Along the lagoon beach there is a series of sand dunes, some as high as 25 feet, that decreases in elevation southwest along the beach. Behind the dunes, to the east, the surface settles gently into a low, relatively flat depression. The elevation here is from 6 to 10 feet. Dunes are absent along the ocean side and elevations here do not exceed 15 feet.

Presently the dominant features on the island are man-made: the 625-foot LORAN tower and transmitter building in the central plain, the 70-foot-high radar reflector on a dune along the southwest beach, the 4,000-foot runway, and the building complex near the center of the island.

A dense growth of _Scaevola taccada_ covers much of the island except for the man-made open areas and the natural central plain

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where only low herbaceous plants grow. A total of 46 vascular plant species has been recorded; the majority (31) was intentionally or accidentally introduced.

Sixty-six species of birds have been recorded from the atoll; 15 breed there, 6 are common visitors, 7 are regular visitors in small numbers and 38 are accidental. The Hawaiian Monk Seal and Polynesian Rat are resident species, while another seven mammalian species have been recorded. Small numbers of two gecko species live on Green Island and Green Turtles visit the atoll infrequently.

Prior to 1950 Kure Atoll was visited infrequently, especially by biologists. In the 19th century at least 13 different ships came to the atoll and another 4 wrecked upon the reef. These visits were generally brief and no permanent settlements were made. Visits were more frequent in this century and the first systematic bird observations were made in 1915. Detailed observations were also made in 1923, 1957, 1958, and 1959.

In June 1960 the construction of a United States Coast Guard LORAN station was begun; it was completed in April 1961. This was the first permanent settlement on the island. Presently (1970) 24 men live there.

In the 1960's visits by biologists became more frequent and culminated in the detailed survey of the atoll by the Pacific Ocean Biological Survey Program (POBSP) of the Smithsonian Institution from 1963 to 1969. This survey substantially increased our knowledge of the atoll's fauna (especially birds), not only of what species occurred there but of their biology and movements. This work composes the bulk of this paper.

HISTORY

19th Century

Prior to 1827 Kure Atoll was probably visited by at least 6 different ships and received a different name after each visit. In 1799 Captain Don M. Zipiani, commanding the Spanish vessel Senhora del Pilar, found an island three miles from north northeast to south southwest in latitude 28°9'N longitude 175°48'E and named it Patrocinio (Findlay, 1870). Krusenstern (1835) lists four islands in the vicinity of Kure (Staver at 28°N 181°20'E, Ocean at 28°10'N 181°20'E, Massachusetts at 28°20'N 181°20'E, and Cure at 28°27'N 181°35'E) and states that they were in fact all the same island. Since there are no details of any of these visits it is impossible to state unequivocally that they were Kure Atoll or which one actually discovered the atoll.

The first visit definitely to Kure Atoll was in 1825 when the schooner Tartar, under the command of Captain Benjamin Morrell, Jr., spent two days (Morrell, 1841). On 11 July the ship left Pearl and Hermes Reef and sailed westward. The next day it arrived at Byer's Island (probably Midway) which they left at 6 p.m. At 4 a.m. on 13 July 1825, approximately the time it would take to sail from Midway to Kure, they arrived at an unknown island.

> At 6 a.m. we were within half a mile of the breakers, and no land in sight. We bore up and passed around the west end of the reef, which was distant about two miles. We then hauled on a wind under the lee of the reef at the rate of seven miles an hour, for two hours in a north-by-west course, we saw the land from the mast head, bearing north-west. We immediately kept off for it, and at 10 a.m. we were close in with a small low island, covered with sea-fowl, and the shores of which were lined with sea elephants. Green turtles were found here in great abundance, and two hawk's bill turtles were seen. This island presents all the usual indications of volcanic origin.
>
> On the west side of this island there is a reef which runs off about fifteen miles, while that on the south-east side extends about thirty miles, in the direction of south-south-east. These reefs are formed of coral, and afford good anchorage on the south-west side, but on the east side the water is bold close to the reef. The island is low, being nearly level with the surface of the sea, and about four miles in circumference. Its centre is in lat. 29°57' north, long. 174°31' east (Morrell, loc. cit.).

They left on Thursday the 14th of July. Although the position is incorrect, it is obvious from the sailing times and description that this was Kure Atoll. Krusenstern (1835) named it Morell (sic) Island.

In 1827 Captain Stanikowitch, of the Russian shop Moller, found a small, low, dangerous island at 28°27'N, 178°23'30" (Sharp, 1960). It was this discovery that prompted Krusenstern to synonomize all the previous names under the single appellate of "Cure Island."

In 1837 the first of many ships wrecked on the reef surrounding the atoll. At 11:30 p.m. on 9 June the British whaler

Gledstanes, Capt. John R. Brown commanding, struck the northern reef (Sandwich Island Gazette, 1837). Three boats were lowered and the captain, officers, and crew laid off the wreck until daylight when they rowed about fifteen miles to land (presumably Green Island). They returned to the wreck and were able to salvage a little bread, a few clothes, eighteen casks of flour, one cask of salt provisions, and a few casks of oily water.

Most of the time the crew was engaged in the construction of a small vessel from the remains of the Gledstanes. On 12 October the vessel was launched and named the Deliverance. Three days later Capt. Brown, the Chief Mate, and eight men sailed for Hawaii. Sometime in November they arrived in Honolulu and several months later the remaining crew was brought off the atoll by a vessel dispatched by the H.B.M. Consul in Honolulu (Ibid.).

Capt. Brown described the island as such:

> The island in lat. 28°22'N and long. 178°30' W, which I suppose to be Ocean Island, is about three miles in circumference. It is composed of broken coral and shells, and is covered, near the shore, with low bushes. In the season, it abounds with sea-birds and at times, there is a considerable number of hair seals. There is always an abundance of fish, and in a great variety. The highest part of the island is not more than ten feet about the level of the sea. The only fresh water is what drains through the sand after the heavy rains. From the specimens of dead shells lying about the beach, there appears to be a great variety of shell (Hawaiian Spectator, July 1838).

In May 1838 Capt. Daggett of the ship Oscar saw Cure's Island in latitude 28°15' N, longitude 177°35' W and noted that the reef extended westward (Sandwich Island Gazette, Dec. 22, 1838). It was noted in this article that Cure's Island was a little to the east of Ocean Island, suggesting that there was still some confusion as to the exact location of Kure Atoll.

On 24 September 1842 at 2:30 a.m. another whaler, the Parker from New Bedford, Massachusetts, struck the reef about 8 miles north northwest from the center of Ocean Island (Temperance Advocate and Seamen's Friend, June 27, 1843). The ship was completely wrecked and four men were lost. Only a peck of beans and 20 pounds of salt meat were saved. After struggling for eight days and seven nights they reached land on a raft they had constructed from the wreck of the Parker.

Here they found some remains of the Gledstanes which served for firewood and building materials. From the Parker they obtained some pieces of copper which were made into cooking utensils.

While on the island the men killed 7,000 sea fowl and about 60 seals for food (Whalemen's Shipping List, November 7, 1843). A dog remaining from the Gledstanes' wreck was on the island and after several weeks they caught and ate it. Every morning and evening the captain conducted religious services and on Sabbath mornings a bethel flag was hoisted (Ibid.).

On 16 April 1843 the James Stewart of St. Johns, New Brunswick was spotted, but the wind carried it to the south of the island. The next day Capt. Smith, the carpenter, the cooper and cabin boy boarded the ship. Before leaving they left 20 pounds of bread and 20 pounds of beef for each remaining man, besides a barrel of salt, and cotton cloth sufficient for one shirt each and numerous minor articles of essential benefit. The captain of the James Stewart promised to return to pick up the remaining crew after the end of his cruise. This proved to be unnecessary, however, for on 2 May the whaleship Nassau, Captain Weeks commanding, arrived and took the remaining crew off the island.

In late June or early July 1859 the American barque Gambia visited Kure. Capt. N.C. Brooks reported (Brooks, 1860):

> ...consisting of three small islands or rocks, surrounded by a reef thirty miles in circumference.... A bank makes off round this reef at a distance of a mile with twenty-five to thirty fathoms water. The three islands are on a line East and West. The surf makes off to the East a quarter of a mile, and to the N.W. twelve miles. The reef opens to the S.W. for about three miles. The best anchorage is found by bringing the N.W. point of the breakers North, in water from seven to twelve fathoms, one mile from the reef. Currents sets north and south about two knots. Tide rises twenty-two inches. They can be approached from any point, and can be seen from the masthead eight miles, being about twenty feet high and covered with bushes. On the north end of the large island, which is 3 1/2 miles long by 1 1/2 wide, there has been a lagoon, but it is now overgrown. On this island I found the remains of the wreck of a merchantman, which had evidently been recently lost. She was not an American vessel. I found the beach strewn with remains of the cargo and wreck, consisting of bamboos, China mats, and tubs. The vessel was undoubtedly from China or Manila. On the north end I found washed ashore the broadside of the vessel, that had the fore and main channels on from plankshear to below 6 sheets copper. I brought away copper and door locks, which I found on her cabin

> doors on the beach. On the stern of a jollyboat I found the name Issac Holder branded, probably the builder's name. Good water may be obtained on this island. The second island in size is about two miles long and a half a mile wide, with little vegetation, few fowls, and plenty of turtle. The third is a mere sand spit.

Kure Atoll was next visited by the U.S.S. Lackawanna, Capt. William Reynolds commanding. On 31 August 1867 the ship circled the reef and the following report was made (RG 45 National Archives Log of the Lackawanna May 20, 1867 to November 24, 1867).

> Island 14 3/4' in circumference, somewhat oval shaped. Wall extended from middle of green island to NW extreme as at Brooks island, but showing about water to the westward, a low sand island, west of green island as at Brooks but not so high. A large tree with roots on beach. A lower mast of a ship on green island NE corner. Lagoon all shallow water. No sign of entrance or inside anchorage from aloft.

At approximately 4 a.m. on 28 October 1870 the U.S.S. Saginaw, Lt. Commander Montgomery Sicard commanding, left Midway Atoll, after seven months of work, for San Francisco. Before setting sail for California, however, the Captain decided to go to Kure Atoll and confirm its position and look for shipwrecks. Early in the morning on 29 October the ship was resting on the northern reef of Kure Atoll and taking on water rapidly. The Friend for February 1, 1871, reports that:

> It was in truth, a remarkable shipwreck. The night had been clear straight, with a moderate breeze. The ship was heading direct for an island whose position and distance - and that a short one - were known, approximately if not precisely. She was making not over two and a half to three knots, yet she ran directly, without any particular lack of vigilance, on a reef which was above water, and on which the breakers where dashing furiously.

Nonetheless, Lt. Commander Sicard was cleared of negligence by a board of inquiry.

Since the ship did not break up until several weeks had passed, much gear was salvaged and a comfortable camp was erected on Green Island. Readers are referred to George H. Read's The Last Cruise of the Saginaw for details of life on the island. Much of the time was spent building a gig and another larger boat to effect their rescue.

On 18 November 1870 the gig, with Lt. J.C. Talbot, Peter Francis, James Muir, John Andrews, and William Halford aboard, left Kure for Honolulu. After a long, arduous journey they sighted Kauai on 18 December. One day later the gig went through the surf and capsized killing all crew members except Halford (The Friend, Jan. 1, 1871). When news of the Saginaw reached Honolulu the American Consul dispatched the Kona Packet to rescue the crew and the Hawaiian King dispatched the steamer Kilauea for the same purpose because he was afraid that the slower-moving Kona Packet would not arrive in time. On 3 January 1871 the Kilauea reached Kure and the next day the crew was taken off the island.

The next recorded visit to Kure was in 1881 when the British schooner Ada spent about two days there from 30 December to 1 January collecting turtles, bêche-de-mer, and eggs. They took 6 turtles, 140 beche-de-mer, plenty of bird eggs, and at least 2 rotten turtle eggs (Hornell, 1934).

On 15 July 1886, the Dunnottar Castle, H.A. Martin captain, bound for Wilmington, California, from Sydney, Australia, wrecked upon the reef of Kure Atoll (Honolulu Almanac and Directory, 1887). Nine days later Mr. Norman and six men left in a boat to get relief from Honolulu. After a journey of about 52 days they arrived at Hanalei, Kauai, and on 14 September the Waialeale left Honolulu to rescue the crew. However, the remaining 22 crewmen had been taken off the island by the Birham Wood of St. John's, New Brunswick. During their brief stay on the island they evidently ate turtles and seafowl.

The Waialeale arrived on 20 September and the island was taken possession of by James H. Boyd for King Kalakaua of Hawaii with the following words:

> I Colonel James Harbottle Boyd by the power in me vested by His Hawaiian Majesty King Kalakaua's Commission as His Special Commissioner do in His Royal Name take formal possession of Ocean Island or Moku Papapa as a part and portion of His Royal Domain.
>
> Done at Ocean Island or Moku Papapa this 20th day of September A.D. 1886.
>
> Jas. H. Boyd
> His Hawaiian Majesty's
> Special Commissioner

(Hawaiian Archives, Letters Book 28, p. 298).

The next day the relief party erected a house 20 feet by 12 feet with a corrugated iron roof, placed water tanks, and

sowed seeds of alegeroba, pride of India, Kamaui, monkey pod, noouki, and ohia trees. They reported that the island is now barren of trees with a stunted vegetation. The trunk of a tree fifteen inches in diameter and four feet high was found standing on the island. On 21 or 22 September the Waialeale left the atoll.

Apparently in 1889 Captain Johnson of the Norma visited Kure before going to Midway to rescue the Wandering Minstrel castaways (Cameron, 1928). He found that the building had blown down and was mostly buried in the sand.

There were also two visits in the late 1880's or 1890's for which details are lacking. John Cameron of the Ebon reported that the island was sandy and barren with a very exposed anchorage (Cameron, op. cit.). He went ashore to see the building erected by the Hawaiian Government in 1886 but found only sheets of corrugated iron, which he took back to the ship, scattered about. He reported that he had heard that a party of Japanese feather hunters had stolen the provisions.

In the Log of the Kaalokai (1909) Captain F.D. Walker reports that the provisions from the shelter were stolen less than twelve months after it was erected. He also has a picture of the remains of the shelter and of the lagoon. No mention of any visit was made in the text.

On 15 February 1894 the North Pacific Phosphate and Fertilizer Company leased Kure Atoll for 25 years at a rental of a dollar a year. The company was also granted the exclusive rights to mine the phosphate deposits thereon, provided a royalty of 50 cents a ton was paid to the Hawaiian Government. However, if mining was not begun within five years of the signing of the contract, the lease would be withdrawn. Since evidently no guano was mined at Kure, the lease expired in February 1919.

Kure Atoll was acquired by the United States of America as part of the Territory of Hawaii on 7 July 1898.

20th Century

In contrast to the 19th century, most 20th century visits to Kure were purposeful. The first systematic bird observations were made in March 1915 and April 1923 (Biological Survey Section).

On 18 May 1905 the U.S.S. Iroquois, Lt. Commander A.P. Niblack commanding, visited the atoll for about six hours, sent a boat ashore, found no people, and then left for Midway (RG 24 Log of the U.S.S. Iroquois 1905). An equally brief visit was

made on 23 January 1910 by the Thetis, Captain W.V.E. Jacobs commanding (RG 26 Log of the Thetis 1910). A party landed on both islands, found a number of sea lions, numerous birds, no people, and no sign that people had landed there recently.

Kure Atoll became part of the Hawaiian Islands Reservation on 3 February 1909 when President Theodore Roosevelt signed Executive Order 1019 reserving Kure Atoll for the use of the Department of Agriculture as a preserve and breeding ground for native birds.

A party from the U.S.S. Hermes, Lt. John T. Diggs commanding, was unable to land due to heavy surf on 15 September 1918. This was unfortunate since they were observing birds. They reported:

> Ocean Islands consists of three islands, lying fifty-six miles west of Midway and reminds one very much of Midway in formation, with another natural reef breakwater inclosing them, about fourteen and three quarter miles in circumference.
>
> Green Island, the first of the three approached, is about twenty feet above the sea line at its highest end and is covered with shrubbery along the top level. It is about one and a half miles long by three quarters of a mile wide and appears alive with birds of about the same species that inhabit the other islands. The Laysan Albatross, White Tern, White-breasted Petrel, boobies, Black-footed Albatrosses were observed flying around the vessel.
>
> To the westward of Green Island appear two more Islands composed of sand, the westernmost of which is about ten feet above sea level, upon which no vegetation could be observed (RG 45 Report of Commanding Officer to Commandant 14th Naval District).

The U.S.S. Marblehead, Capt. H.K. Cage commanding, passed by the atoll on 24 April 1928 and reported that there were no signs of habitation or wrecks on the reef (RG 80 Log of the Marblehead 1928).

During the 1930's and early 1940's several ships visited the atoll briefly. As part of the United States Navy's Fleet Problem XVI, the U.S.S. Dobbin visited Kure from 12 to 22 May 1935 and the U.S.S. Ramsay was there 15 and 16 May 1935 (RG 24 Logs of the Dobbin and Ramsay 1935).

On 13 June 1940 the U.S.S. Childs, Lt. Commander J.L. Pratt commanding, surveyed the lagoon and island, and installed permanent shoal markers. They reported no evidence of recent activity except a wrecked Japanese boat still on the northern part of the reef (RG 24 Log of the Childs 1940 and RG 37 Aircraft Advanced Base Report of U.S.S. Childs). The HMAS Manoora was there in February 1941 (Pacific Island Pilot, Vol. III, 1946), the U.S.S. Saury and U.S.S. Spearfish on 26 August 1941 (RG 24 Logs of the Saury and Spearfish 1941), and the U.S.S. Preble on 20 April 1942. The Preble reported that they saw the remains of two fires and a small lean-to on the southwest end of Green Island (U.S. Navy, War Diary U.S.S. Preble).

On 23 June 1934 the USCG ship Itasca, J.S. Baylis commanding, briefly visited the atoll. The captain, officers, and guests left the ship and investigated the island (RG 26 cruise report for the Itasca for the month of June 1934). They reported thousands of birds, 50 or 60 seals, no inhabitants or boats, and hundreds of glass balls, one of which was thrown overboard on 6 April 1931 east of Honolulu by the Chichibu Maru.

On 20 February 1936 President Franklin D. Roosevelt signed Executive Order 7299 placing Kure (Ocean) Island and surrounding reef under control and jurisdiction of the Secretary of the Navy for naval purposes.

From 5 to 13 April of that same year the U.S.S. Oglala, Commander F. Cogswell commanding, and the U.S.S. Quail, Lt. H.T. Wray commanding, surveyed the island and the lagoon for possible use as a military airfield (RG 37 Report of the Survey of Kure Island and Pearl and Hermes Reef). Under the direction of Lt. W. Nyquist they made soundings in the lagoon, astronomical observations, and tide observations. They reported:

> Green Island is on the southeastern side of Ocean (Kure) reef. The island lies in a northeast southwest direction and is about 1 1/2 miles long and 1/2 mile wide. It is covered with very irregular sand dunes which rise to about 20 feet. These sand dunes are covered with a thick growth of wild magnolia 6 to 8 feet high. The beach on the lagoon side is about 75 feet wide at high water and a camp could be established. There is quite an area where boats can easily beach. Quite a few seals and birds inhabit this island. One turtle was seen. The lagoon abounds with mullet and rock fish...It is covered with wild magnolia and nesting albatross.

The Japanese steamer Stato Maru with a crew of 25 to 30 men wrecked at Kure Atoll on 25 February 1938. Presumably they were taken off the island by the Japanese vessel Aomori.

I have no records of any activity at the atoll during World War II but undoubtedly it was visited by naval vessels and possibly by groups from Midway. Walter Lord (1967) reports that as part of their invasion of the Hawaiian area, the Japanese planned to build a miniature submarine base there.

Bailey (1952) reports seal counts made at Kure in summer 1949, 2 August, and 12 October 1951 by people from Midway Atoll.

On 17 November 1952 President Harry S. Truman signed Executive Order 10413 restoring Kure Atoll to the Territory of Hawaii. The Navy had the right to maintain a radar reflector there. Apparently this reflector was built in 1955, but I have no details of its construction.

The 1950's saw an increase in the number of visits to the atoll. Most of these were made by United States Fish and Wildlife Service personnel and are discussed in the Biological Survey Section.

The most lasting change at Kure was the establishment of a United States Coast Guard LORAN (Long Range Navigation) station. Construction began in June 1960 and was completed in April 1961. The major features of the station are a barracks, a signal/power building, a transmitter building, a pumphouse, seven fuel tanks, a 4,000-foot-long runway and a 625-foot-high LORAN tower.

On 17 March 1961 the station was commissioned with a crew of 1 officer and 23 enlisted men. The station is still operating (1970) as part of the world-wide aids to navigation system of the U.S. Coast Guard. Kure Atoll is also a Wildlife Refuge under the jurisdiction of the Hawaii Fish and Game Department. Under the terms of the lease from the Hawaiian Commissioner of Public Lands, the Coast Guard will protect "all species of turtles and the Hawaiian monk seal, and so far as practicable and with Coast Guard operational requirements the *Lepturus repens*, *Solanum nelsoni* var. *intermedium*, and all other animal (except rodents), bird and vegetable life on the island."

DESCRIPTION

Kure Atoll is situated on the top of a submerged volcano, part of the submarine Hawaiian Ridge which extends southeastward to the high mountainous island of Hawaii. Drilling at Midway

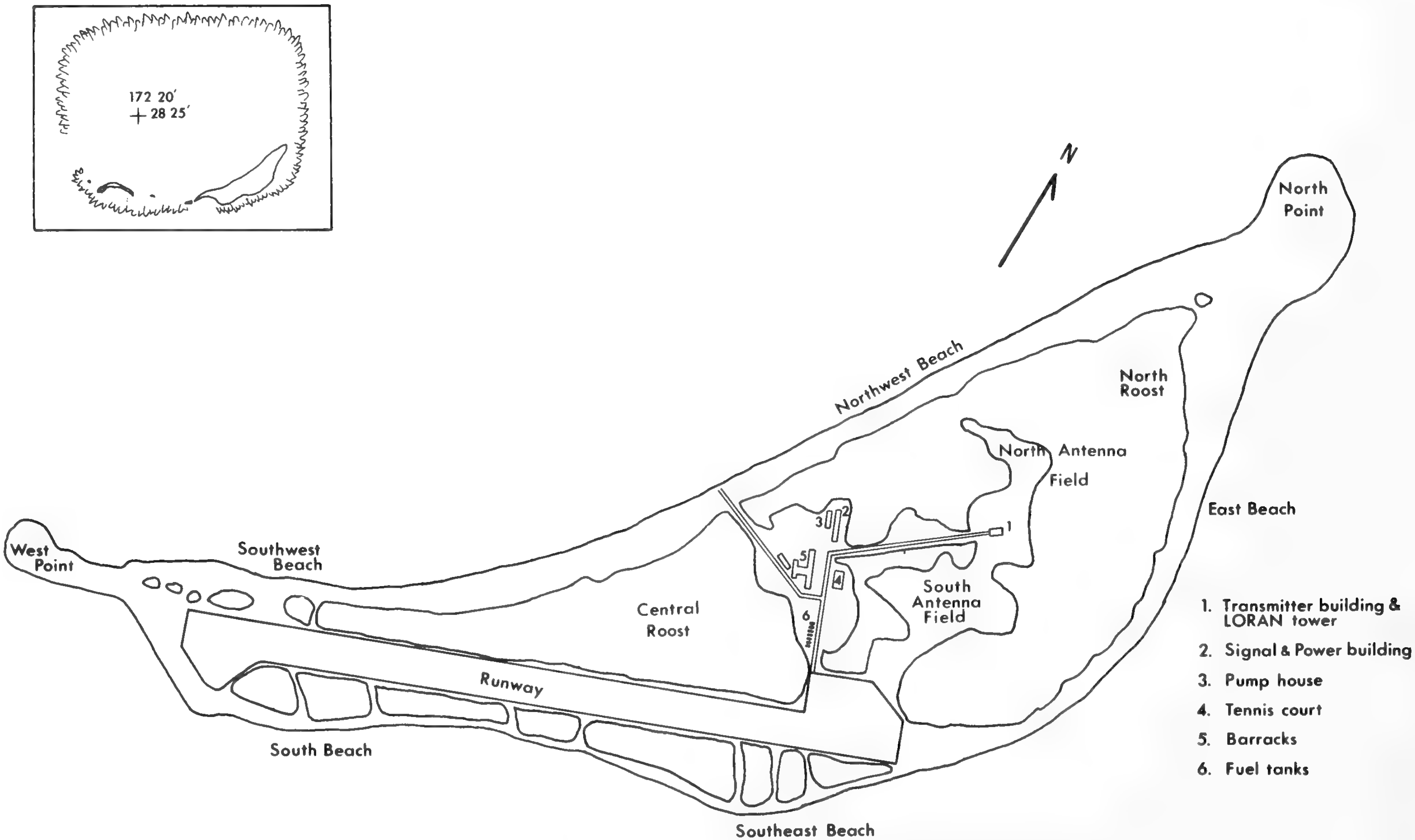

Figure K-1. Green Island, Kure Atoll.

Atoll indicated that the reef there dates back to Miocene times, some 28 million years ago (Ladd _et al_., 1962).

The atoll is nearly circular with the outer reef almost completely enclosing the lagoon except for passes on the south-western side. It is oriented on a northwest to southeast axis and has a maximum diameter of 9.5 kilometers. Unusual features are the elongated reef patches and coral ridges in the lagoon and the presence of an emergent rock ledge on the outer reef. The ledge is composed primarily of coralline algae and of algally bound and encrusted pieces of coral and other carbonate materials, mainly aragonite and magnesium calcite. This material was dated by the Carbon-14 method at 1,480 ± 250 years BP. The reef, comprising an area of about five square kilometers, is composed of coralline algae and corals (Gross _et al_., 1969).

The lagoon has a maximum depth of fourteen meters. Six square kilometers of the lagoon terrace are greater than five meters high and forty square kilometers are less than five meters high (Gross, _op. cit_.).

On the outer reefs, the lagoon terrace, and seaward island beaches, gravel and coarse sand are the dominant textural types, while on the lagoonward side coarse sand or medium to fine sand generally predominate. In the lagoon, medium to fine sand and fine debris are the common sediment (Gross, _op. cit_.).

Green Island, the only permanent land mass in the atoll, is located near the fringing reef in the southeast sector (Figure K-1). Crescentric in shape with the long axis curving from north to west, it is 1.43 miles in greatest length and 0.37 miles in maximum width. Sandy points, whose shapes and sizes vary seasonally and with local weather conditions, are present at both ends of the island.

Standen (ms.) studied the changes at the north point from 7 February to 7 March 1965. His results are briefly summarized here. During the first two days the point lengthened about 100 feet. On 18 February the point had grown by another 25 feet, but strong wave action had eroded away a narrow section and the last 50 feet were separated from the main body of the island at high water. On 6 March the point was 100 feet longer than on 27 February and 200 feet longer than on 9 February and it curved westward. A storm on the night 6 to 7 March washed the entire point away. Standen concluded:

> First, wind direction and the wave action associated with it are key factors in determining island shape, especially regarding availability of material upwind to be transported. With the main body of land to

the upwind side, waves are provided with a large source of sand. Stronger winds may also initiate wave action that picks up and carries sediments from the lagoon bottom. Waves from a direction with no source of material for transport become erosive agents to small islands at a rate increasing with their velocity and size.

Wind speed determines where and how sand will be deposited by water currents. Waves and currents driven by winds less than Beaufort 4 deposit sand parallel to the wind in shallow areas to the lee of already existing islands or on sandbars. Waves and currents driven by winds above Beaufort 4 deposit sand perpendicular to the wind or parallel to the wave fronts. Thus the main axis of the island is perpendicular to the strongest waves, i.e., northwest where lagoon wave fetch is greatest. Vertical growth of the island through wave action occurs when the beach runs at right angles to the wind and thus the wave fronts and when the winds are strong enough to generate waves which cast sand high on the beaches (farther back) without breaking entirely over the island.

Any new sequence of wind directions may temporarily cause a difference in the amount of transported material owing to new sand recently deposited upwind. The usual sequence of winds is clockwise with the passage of lows, but occasional reversals do occur.

In summer the west point is well developed to the west and the north point is hooked slightly to the northwest. During the winter, however, the west point is typically absent and the north point curves to the east.

A sandy beach encircles the entire island. On the ocean side it is narrow and fairly steep with much coral rubble and other debris strewn about, especially on the southern side. Further north it widens and the slope is gentler. The lagoon side is wide, as much as 200 feet, and considerably less steep than the ocean side. Here the sand is finer than on the ocean side. In winter water may wash up to the edge of the vegetation around the entire island. Exposed coral boulders are present along the southern beach and near the west point.

Along the lagoon beach there is a series of sand dunes, some as high as 25 feet, that decreases in elevation southwest along

the beach. Behind the dunes, to the east, the surface settles gently into a low, relatively flat depression. The elevation here is from 6 to 10 feet. Dunes are absent along the ocean side and elevations here do not exceed 15 feet.

Presently the dominant features on the island are man-made: the 625-foot LORAN tower and transmitter building in the central plain, the 70-foot-high radar reflector on a dune along the southwest beach, the 4,000-foot runway, and the building complex near the center of the island. A dense growth of _Scaevola taccada_ and the open central plain are the main natural features.

The area to the south of the runway is relatively level and covered with a continuous growth of _Scaevola_ which is dissected by a series of seven paths leading from the runway to the beach. In contrast, the area to the northwest is rolling with dunes along the lagoon and the runway. _Scaevola_ covers most of this area but there are many open areas (Fig. V-1).

North of the building complex and the runway the terrain is relatively level. In the center of the area is the open central plain, some 20 to 25 acres in extent. It is oriented along a north to south axis. Surrounding this plain of low herbaceous plants is tall, dense _Scaevola_. A series of paths runs through this vegetation.

Figures D1-11 show island scenes and should convey to the reader a better impression of Kure than could ever be expressed in words.

To the west of Green Island are three sandbars known collectively as Sand Island. These islets are variable in size and shape throughout the year. Generally they follow the pattern of the north and west points of Green Island. The largest one may be as long as 400 meters and as wide as 20 meters. Birds breed only on this largest islet. During the winter these islets may wash away.

VEGETATION

Christophersen and Caum (1931) reported 13 species of vascular plants collected at Kure Atoll by the Tanager Expedition. In 1959 Clay (1961) found an additional 6 species and Lamoureux (1961) reported another 23 in 1961. During POBSP studies four previously unreported species were found; thus 46 species of vascular plants have been recorded at Kure Atoll (Table P-1). The majority of these species was intentionally or accidentally introduced during the construction of the LORAN station.

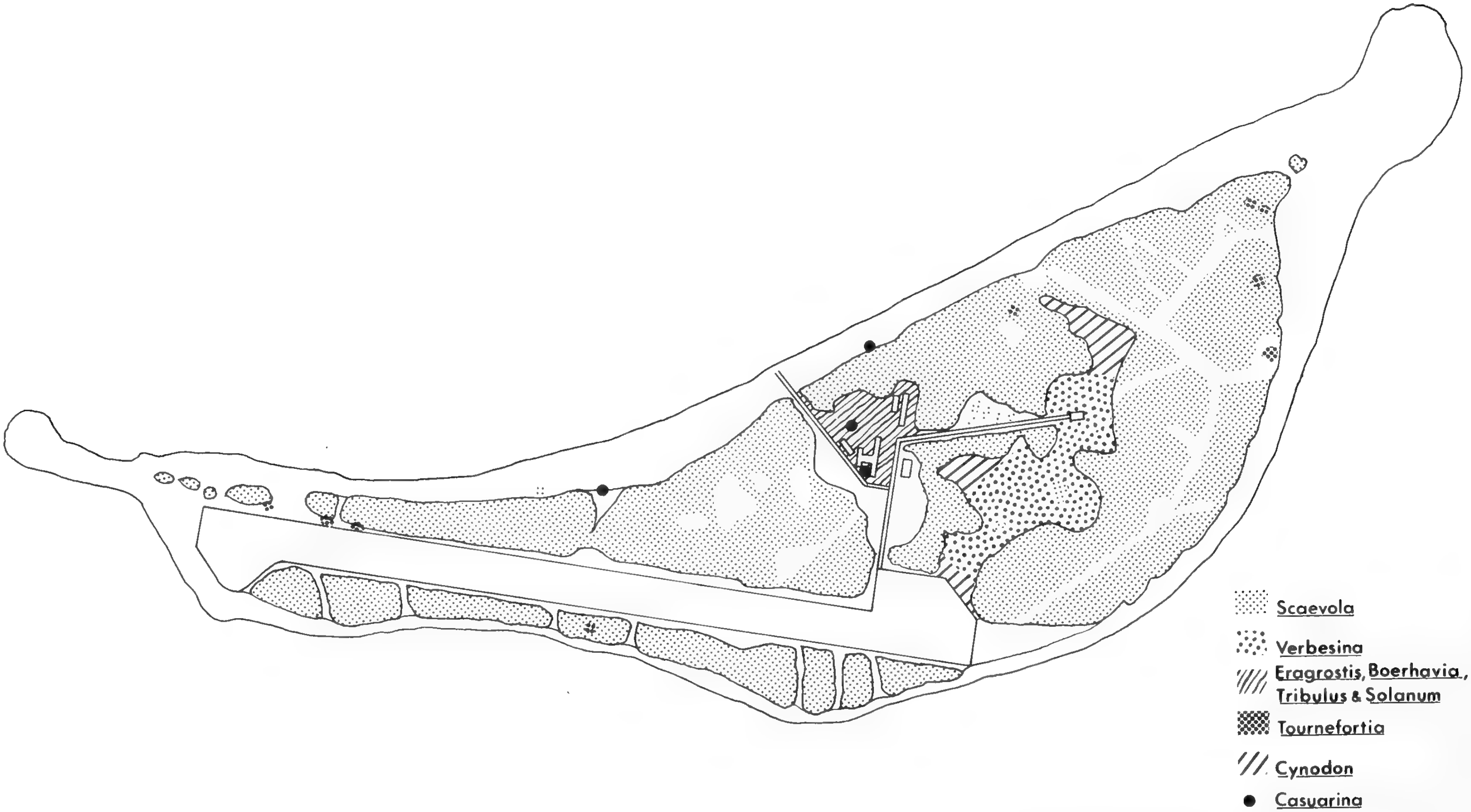

Figure V-1. Vegetation of Green Island, Kure Atoll.

Figure D-1. Aerial view of Green Island, Kure Atoll, looking north, 6 April 1966. Official U.S. Coast Guard photograph.

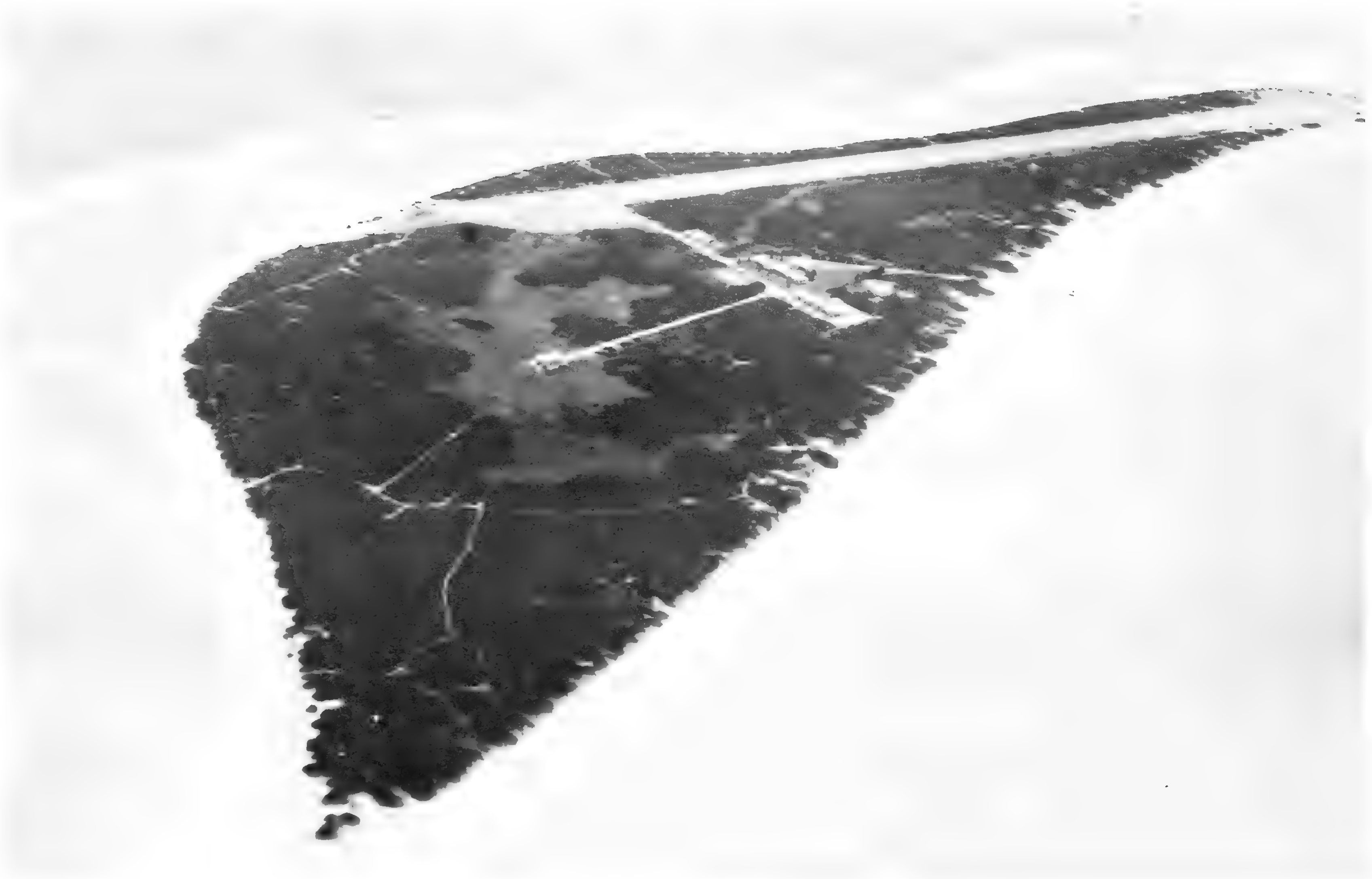

Figure D-2. Aerial view of Green Island, Kure Atoll, looking south, 27 February 1968. Official U.S. Navy photograph.

Figure D-3. Aerial view of building complex on Green Island, Kure Atoll, 13 October 1964. Official U.S. Navy photograph.

Figure D-4. North antenna field from north tower, Green Island, Kure Atoll, 1 July 1968. POBSP photograph.

Figure D-5. Blue-faced Boobies in north antenna field, Green Island, Kure Atoll, 1 July 1968. POBSP photograph.

Figure D-6. Looking towards west point from radar reflector, Green Island, Kure Atoll, 1 July 1968. POBSP Photograph.

Figure D-7. Breeding Red-footed Boobies in central roost, Green Island, Kure Atoll, 1 July 1968. POBSP photograph.

Figure D-8. South beach, Green Island, Kure Atoll, 1 July 1968. POBSP photograph.

Figure D-9. Edge of runway, Green Island, Kure Atoll, 1 July 1968. POBSP photograph.

Figure D-10. Looking towards north point from north tower, Green Island, 1 July 1968. POBSP photograph.

Figure D-11. Sooty Tern colony in south antenna field, Green Island, Kure Atoll, 1 July 1968, POBSP photograph.

Christophersen and Caum (1931) described Green Island in 1923 as

> covered with a dense, almost impenetrable growth of *Scaevola frutescens*..., which averages 5 to 6 feet in height, except in small areas, generally on the tops of the sand hills, where it is only about waist high and fairly open. In these openings and along the outer rim of the thicket are a few other plants, principally the tall bunch-grass, *Eragrostis variabilis*, and the creeping *Boerhavia diffusa*. Toward the east central part of the islet is a large, open plain, probably 20 to 25 acres in extent, entirely surrounded by the tall *Scaevola frutescens*....With the exception of a few "islands" of *Scaevola frutescens*, scarcely any vegetation in this central plain was over 2 feet high, and most of it was considerably under that height.

Achyranthes splendens, *Tribulus cistoides*, and *Lipochaeta intergrifolia* were found only on the plain, while *Eragrostis variabilis*, *Boerhavia diffusa*, *Lepidium owaihiense* and *Solanum nelsoni* grew on the central plain and in open areas among the *Scaevola*. Two clumps of *Cenchrus agrimonioides* were found, one among *Scaevola* and one on the edge of the central plain. Other plants were found as follows: *Eragrostis whitneyi* grew sparingly on the outer edges of the dunes at the northwest corner; *Lepturus repens* at one spot among *Scaevola*; *Ipomoea indica* on *Scaevola*; and *Sicyos hispidus* on *Scaevola* islands in the central plain and on the inner edge of the scrub.

In October 1959 Clay reported a vegetative condition similar to that recorded in 1923. However, he found *Cynodon dactylon*, *Casuarina equisetifolia*, *Pluchea odorata*, and *Verbesina encolioides* growing near the radar reflector and surmised that seeds of these plants were brought on equipment from Midway Atoll in 1955 when the reflector was built. Two other new species were reported: a young *Tournefortia argentea* growing on the windward shore and *Solanum nigrum* on the central plain.

By the time Lamoureux visited Kure in September 1961 the island had been greatly altered by the construction of the LORAN station. As a result, there were more open areas: along the runway, around the building complex and roads and through the *Scaevola* on the south side of the runway (the remains of the albatross paths built in 1959). He reported (1961) the following changes in these areas:

a. Margins of roads and runway. Boerhavia diffusa has covered most of the margin of the runway, with Tribulus cistoides and some weedy grasses occurring as scattered individuals. Along the roadsides Boerhavia is somewhat less abundant with a larger proportion of weeds.

b. Albatross runways. Covered with Boerhavia.

c. Clearings around living quarters. Gnaphalium sandwicensium is extremely abundant in areas where Cynodon dactylon has not been planted. Euphorbia glomerifera, Emilia javanica, Conyza bonariensis, and Eragrostis amabilis were found only here.

d. Clearing around LORAN Tower. A series of cleared strips a few meters wide radiate out from the base of the tower to the guy-wire anchors. These strips cut through most of the eastern part of the central plain. Boerhavia diffusa, Lepidium owaihiense, Lipochaeta integrifolia and Solanum nigrum are moving into these areas.

Twenty-three new species were found on this trip. Only one, Phyllostegia variabilis, was native and had probably been overlooked by earlier observers. Cocos nucifera, Codiaeum sp., Hibiscus sp., Thespesia populnea, Terminalia catappa, Nerium oleander, and Helianthus annuw were cultivated around the buildings while the other new species were found in disturbed areas and were undoubtedly accidentally introduced to the island during construction work. Scaevola was still the most abundant plant and the central plain was still present.

During POBSP studies the vegetation on Green Island remained similar to that found by Lamoureux, although much of it had grown taller. The following is an account of the vegetation on Green Island in 1968 and applies to most years POBSP personnel worked on the island.

Scaevola taccada covers most of the island (Fig. V-1) except for the original central plain and man-made open areas. The extent of these areas varies. For example, after the station was built, most of the area under the LORAN tower and its supporting guywires was devoid of Scaevola. By 1963, when POBSP studies began, most of this area, except for that portion of the central plain where Scaevola has never grown, was again covered with this species. Given enough time, the majority of these man-made areas would again by covered with Scaevola.

There are three types of open areas--the central plain, the area around the buildings, and the other man-made areas. On the central plain, the dominant species are Eragrostis variabilis, Boerhavia diffusa, Lepidium owaihiense, Tribulus cistoides, Solanum nelsoni, Sicyos hispidus, and Verbesina encelioides. Cenchrus echinatus, Achyranthes splendens, Ipomoea indica, Solanum nigrum and Lipochaeta integrifolia also grow there.

Around the buildings Cynodon dactylon was planted as a lawn grass and is now the dominant ground cover; most native species are rare or lacking. Cocos nucifera, Casuarina equisetifolia, Hibiscus sp., Thespesia populnea, Terminalia catappa, Nerium oleander, and Pluchea odorata were planted as ornamentals.

In the other open areas the commonest species are Eragrostis variabilis, Boerhavia diffusa and Gnaphalium sandwicheum. Elusine indica, Tribulus cistoides, Solanum nelsoni, Solanum nigrum, Sonchus cleraceus, and Verbesina encelioides are also common.

Besides Scaevola, Casuarina equisetifolia and Tournefortia argentea are the major shrub or tree species on the island. The former species is present in three groups around the barracks and in one group along the southwest beach near the radar reflector. These trees are about 20 feet tall. Great Frigatebirds, Red-footed Boobies, and Black Noddies commonly roost in them but no birds nested in them during POBSP studies. Tournefortia is found at the north end of the island (4 trees about 10 feet high), northwest of the central plain (1 tree about 10 feet tall), south of the runway (1 tree about 10 feet tall), and along the southwest end of the runway (3 trees 3 to 4 feet tall) (see Fig. V-1). Red-footed Boobies and Great Frigatebirds breed in the northernmost tree along the northeast beach, while the others are utilized only for roosting. Scaevola provides roosting areas, breeding areas, and/or shelter for most avian species.

Verbesina encelioides is the most important of the introduced species to the island's avifauna. First found in October 1959 growing near the radar reflector, it is now widespread and growing in most of the open areas, mainly the central plain and near the radar reflector. Growing in dense stands and up to 4 feet tall, it is a potential danger to the island ecosystem, especially its ground nesting birds and native vegetation. Birds have difficulty moving through Verbesina stands and when the plant becomes dense enough are no longer able to breed where it grows. Presently the breeding habitat of the Blue-faced Boobies is threatened in such a manner. Other plants cannot grow under it, so native plant species in the central plain are also threatened. The range of this species continues to expand rapidly on the island.

Other species of importance to the birds include Boerhavia diffusa, Tribulus cistoides, and Solanum nelsoni. These plants are used as nesting materials by Red-footed Boobies and Great Frigatebirds.

There is a definite seasonal growth and reproductive period for plants, mainly from June through October. In summer, for example, Tribulus and Boerhavia cover the cleared breeding sites of the Blue-faced Booby and probably prevent the building of nests at this time. There is little growth from November through March. During this period wind and sand may scour and defoliate Scaevola, primarily on the windward side and to a lesser extent elsewhere on the island.

Table P-1. Vascular plants recorded at Kure Atoll by various people.

	Christophersen and Caum	Clay	Lamoureux	POBSP
Pandanaceae				
Pandanus sp.			x	
Gramineae				
Brachymenium sp.				x
Cenchrus agrimonioides Trin. var. laysanensis	x		x	x
Cenchrus echinatus L.			x	x
Choloris inflata Link			x	x
Choloris virgata Swartz			x	x
Cynodon dactylon (L.) Pers.		x	x	x
Digitaria sanguinalis (L.) Scop.			x	
Digitaria henryi Rendle				x
Eleusine indica (L.) Gaertn.			x	x
Eragrostis amabilis (L.) W & A.			x	
Eragrostis variabilis (Gaud.) Steud.	x	x	x	x
Eragrostis whitneyi var. caumii Fosb.	x	x	x	x
Lepturus repens (Forst.) R. Br.	x	x	x	x
Setaria verticellata (L.) Beauv.			x	x
Cyperaceae				
Cyperus rotundus L.			x	x

Table P-1. (continued)

	Christophersen and Caum	Clay	Lamoureux	POBSP
Palmae				
Cocos nucifera L.			x	x
Casuarinaceae				
Casuarina equisetifolia		x	x	x
Amaranthaceae				
Achryanthes splendens var. *reflexa* Hbd.	x		x	x
Amaranthus spinosus L.				x
Nyctaginaceae				
Boerhavia diffusa L.	x	x	x	x
Caryophyllaceae				
Spergularia marina (L.) Griseb.			x	x
Cruciferae				
Lepidium owaihiense C. and S.	x	x	x	x
Lepidium virginicum L.				x
Zygophyllaceae				
Tribulus cistoides L.	x	x	x	x
Euphorbiaceae				
Codiaeum sp.			x	
Euphorbia glomerifera (Millsp.) Wheeler			x	x
E horbia hirta L.				x
Malvaceae				
Hibiscus sp.			x	
Thespesia populnea (L.) Sol.			x	
Combretaceae				
Terminalia catappa L.			x	
Apocynaceae				
Nerium oleander L.			x	x
Convolvulaceae				
Ipomoea indica (Burm.) Merr.	x	x	x	x

Table P-1. (continued)

	Christophersen and Caum	Clay	Lamoureux	POBSP
Boraginaceae				
Tournefortia argentea (L.F.)		x	x	x
Labiatae				
Phyllostegia variabilis Bitter			x	x
Solanaceae				
Solanum nelsoni Dunal	x	x	x	x
Solanum nigrum L.		x	x	x
Cucurbitaceae				
Sicyos hispidus Hbd.	x	x	x	x
Goodeniaceae				
Scaevola taccada	x	x	x	x
Compositae				
Conyza bonariensis (L.) Cronq.			x	x
Emilia javanica (Burm.) Rab.			x	x
Gnaphalium sandwicheum Gaud.			x	x
Helianthus annuw L.			x	
Lipochaeta integrifolia Gray	x	x	x	x
Pluchea odorata (L.) Cass		x		x
Sonchùs cleraceus L.			x	x
Verbesina encelioides (Cav.) B. and H.		x	x	x

CLIMATE

The climate at Kure is subtropical marine and is influenced by two main air masses and by the surrounding ocean where surface variables are relatively small. For example, sea surface temperatures vary from a low of 69°F. in February to a high of 80°F. in August and September, and salinities from 35.2‰ in April to August and 35.0‰ in November to February (Seckel, 1962).

Most of the year Kure is in the path of the northeast trade winds from the Pacific subtropical anticyclone, but in the winter

it is on the southern edge of the Aleutian low, with resultant westerly winds. Table C-1* lists the wind direction at Kure for the years 1961 to 1968. From November to February winds were variable, with a strong westerly component which in some years was not well-developed. Winds were again variable from March to June and September to October, but with a major easterly component. The northeast trade winds were best developed in July and August when almost all winds came from the east.

Windspeeds ranged from 0 to 8 on the Beaufort Scale (0 to 46 knots), with a yearly average of about 2 (4 to 7 knots). From 1961 to 1968 average semi-monthly windspeeds (Table C-2) varied from 1.5 to 4.0 (2 to 18 knots). Although there was no consistent yearly pattern, there was a tendency for the strongest winds to occur in winter and early spring, and the weakest winds in summer. In 1967 windspeed varied little throughout the year.

Although there is yearly variation in the average semi-monthly temperatures (Tables C-3 and 4), the pattern of temperature change throughout the year is the same. The average maximum varies about 20°F., from 65°F. to 85°F., and the average minimum varies about 17°F., from 58°F. to 75°F. The absolute variation was 39°F. to 99°F.

From December through April the average semi-monthly maximum is about 70°F., in May, June, and November between 70°F. and 80°F., and from June through October 80°F. to 90°F. The average semi-monthly minimum is between 60°F. to 65°F. from December through May, between 70°F. and 75°F. in November.

January and February are usually the coldest months and July, August, and September the warmest ones. In 5 of the 7 years of POBSP study the average temperature began to increase in May, in one year in June, and the other in April. It began to decrease in September in 4 years and in October in 3 years.

Since rainfall data were not collected at Kure, the Midway Atoll data were used (Table C-5). As with other climatic parameters, rainfall was variable from year to year. Some years the wettest months were in the summer, in other years in winter.

At Midway rainfall averages about 40 inches annually. On the average it rains 12 days each month. March is the driest month and December, January, and February are the wettest months. Heavy rainfall is most common; light rain and drizzles are almost unknown. Rain occurs on only 6% of all hourly observations. Days

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* Weather data were extracted from the station logbooks. Observations were made at four-hour intervals.

with 0.02 to 0.05 inches of rain are most common, days with 0.06 to 0.10 are next commonest, followed by days with 0.11 to 0.20 inches. Thunderstorms are relatively uncommon, averaging six a year (Standen, ms.).

Table C-1. Wind direction at Kure Atoll by semi-monthly periods, 1961-68 (expressed as percentages).

January 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	-	10.1	0.0	7.1	14.8	6.8	15.6	20.0
31-60	-	8.9	0.0	10.6	2.3	3.5	13.3	10.0
61-90	-	6.7	0.0	11.8	0.0	2.3	13.3	10.0
91-120	-	6.7	0.0	8.2	0.0	2.3	15.6	4.4
121-150	-	4.4	1.1	11.8	2.3	6.8	8.9	5.6
151-180	-	6.7	3.4	12.9	4.6	11.5	14.4	3.3
181-210	-	7.8	15.7	9.4	1.1	23.0	7.8	2.2
211-240	-	7.8	20.2	9.4	19.3	8.1	3.3	12.2
241-270	-	19.1	39.3	8.2	28.4	11.5	3.3	8.9
271-300	-	12.3	18.0	5.9	6.8	11.5	0.0	10.0
301-330	-	8.9	2.2	2.4	14.8	8.1	0.0	11.1
331-359	-	0.0	0.0	2.4	5.7	4.6	4.4	2.2

16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	-	6.5	0.0	2.1	3.2	6.6	12.5	9.4
31-60	-	5.4	0.0	0.0	4.2	2.2	3.1	0.0
61-90	-	4.3	0.0	4.2	2.1	1.1	0.0	1.0
91-120	-	3.2	0.0	12.6	8.4	4.4	1.0	1.0
121-150	-	5.4	3.2	9.5	14.7	8.8	2.1	5.2
151-180	-	7.6	5.3	6.3	14.7	13.2	13.5	5.2
181-210	-	15.2	8.4	13.7	4.2	15.4	31.3	13.5
211-240	-	14.1	32.6	21.1	8.4	8.8	9.4	11.5
241-270	-	20.6	33.7	15.8	11.6	14.3	11.5	26.0
271-300	-	4.3	15.8	12.6	13.7	9.9	4.2	11.5
301-330	-	9.7	0.0	2.1	6.3	14.3	4.2	12.5
331-359	-	3.2	1.1	0.0	8.4	1.1	7.3	3.1

February 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	-	6.9	0.0	3.4	17.9	26.1	15.6	0.0
31-60	-	4.6	0.0	6.8	9.0	14.8	14.4	1.1
61-90	-	6.9	0.0	4.5	6.7	21.6	8.9	0.0
91-120	-	3.4	0.0	5.7	4.5	8.0	3.3	0.0

Table C-1. (continued)

February 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
121-150	-	5.8	0.0	11.4	7.9	5.7	0.0	0.0
151-180	-	2.3	2.3	10.2	16.9	6.8	4.4	4.4
181-210	-	2.3	22.7	18.2	14.6	2.3	7.8	25.3
211-240	-	17.4	20.5	9.9	1.1	3.4	7.8	26.4
241-270	-	24.4	42.0	17.0	1.1	1.1	18.9	31.9
271-300	-	5.8	12.5	10.2	2.2	2.3	11.1	8.8
301-330	-	13.9	0.0	3.4	6.7	4.6	5.6	2.2
331-359	-	5.8	0.0	0.0	11.2	3.4	2.2	0.0

16-28

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	-	10.5	1.3	7.1	12.8	31.6	11.1	0.0
31-60	-	5.2	2.6	3.6	10.3	35.5	16.7	0.0
61-90	-	26.3	0.0	6.0	10.3	19.7	22.2	0.0
91-120	-	7.8	1.3	4.8	7.7	4.0	2.8	0.0
121-150	-	5.2	5.1	13.1	12.8	4.0	2.8	0.0
151-180	-	9.2	12.8	15.5	26.9	0.0	9.7	1.2
181-210	-	7.8	7.7	7.1	5.1	0.0	6.9	17.7
211-240	-	11.8	11.5	16.7	0.0	1.3	4.2	29.4
241-270	-	6.5	37.2	9.5	3.9	1.3	2.8	34.1
271-300	-	2.6	16.7	7.1	2.6	0.0	5.6	11.8
301-330	-	5.2	3.8	7.1	6.4	2.6	8.3	5.9
331-359	-	0.0	0.0	2.4	1.3	0.0	6.9	0.0

March 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	-	17.9	27.8	5.7	6.8	11.4	38.9	7.8
31-60	-	5.6	21.1	8.0	2.3	1.3	10.0	23.3
61-90	-	10.1	7.8	16.1	3.4	6.3	3.3	15.6
91-120	-	8.9	7.8	13.8	3.4	8.9	1.1	6.7
121-150	-	16.8	14.4	13.8	4.6	10.1	5.6	3.3
151-180	-	20.2	6.7	9.2	9.1	26.6	5.6	7.8
181-210	-	2.2	1.1	5.7	10.2	5.1	4.4	12.2
211-240	-	1.1	4.4	2.3	15.9	3.8	4.4	4.4
241-270	-	2.2	0.0	4.6	26.1	15.2	10.0	7.8
271-300	-	1.1	1.1	9.2	8.0	1.3	8.9	7.8
301-330	-	5.6	4.4	9.2	5.7	8.9	5.6	2.2
331-359	-	7.8	3.3	2.3	4.6	1.3	2.2	1.1

16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	7.6	47.3	6.3	16.1	6.3	10.4	14.6	13.1
31-60	2.5	21.5	9.5	33.3	6.3	5.2	4.2	38.4
61-90	3.8	9.6	13.7	19.4	32.3	1.0	36.5	21.2

Table C-1. (continued)

March 16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
91-120	1.3	1.0	7.4	9.7	13.5	1.0	4.2	18.2
121-150	7.6	0.0	5.3	6.5	7.3	1.0	3.1	4.0
151-180	21.5	0.0	5.3	2.2	3.1	13.5	0.0	1.0
181-210	19.0	1.1	3.2	2.2	2.1	18.8	3.1	1.0
211-240	2.5	10.7	1.1	1.1	4.2	14.6	3.1	0.0
241-270	7.6	3.2	6.3	1.1	10.4	6.3	3.1	1.0
271-300	3.8	1.1	21.1	0.0	8.3	11.5	10.4	0.0
301-330	15.2	1.1	17.9	6.5	4.2	9.4	11.5	2.0
331-360	7.6	3.2	4.2	3.2	2.1	7.3	6.3	0.0

April 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	31.2	16.7	25.0	47.8	34.8	16.7	21.1	41.1
31-60	17.6	16.7	18.2	43.3	11.2	3.3	23.3	11.1
61-90	4.7	26.7	3.4	3.3	10.1	3.3	23.3	12.2
91-120	1.2	17.8	3.4	1.1	24.7	4.4	23.3	17.8
121-150	2.4	10.0	6.8	0.0	6.7	1.1	5.6	3.3
151-180	4.7	2.2	1.1	0.0	1.1	16.7	0.0	6.7
181-210	7.1	0.0	1.1	0.0	1.1	8.9	1.1	1.1
211-240	3.5	1.1	4.5	0.0	4.5	4.4	0.0	1.1
241-270	1.2	0.0	4.5	0.0	0.0	7.8	0.0	0.0
271-300	0.0	0.0	10.2	0.0	0.0	14.4	0.0	0.0
301-330	12.9	3.3	15.9	2.2	2.3	16.7	2.2	2.2
331-359	12.9	5.6	5.7	2.2	3.4	2.2	0.0	3.3

16-30

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	15.4	46.5	7.8	48.9	6.8	18.0	33.3	35.6
31-60	18.7	23.3	31.1	37.8	5.7	9.0	14.4	46.7
61-90	27.5	11.6	30.0	13.3	14.8	30.3	10.0	5.6
91-120	7.7	5.8	7.8	0.0	11.4	15.7	5.6	3.3
121-150	3.3	4.6	1.1	0.0	8.0	9.0	8.9	2.2
151-180	2.2	6.9	4.4	0.0	6.8	2.3	1.1	2.2
181-210	0.0	1.2	0.0	0.0	0.0	2.3	3.3	0.0
211-240	3.3	0.0	3.3	0.0	9.1	1.1	6.7	2.2
241-270	1.1	0.0	6.7	0.0	25.0	0.0	11.1	2.2
271-300	2.2	0.0	3.3	0.0	5.7	1.1	2.2	0.0
301-330	10.9	0.0	4.4	0.0	3.4	7.9	1.1	0.0
331-359	8.8	0.0	0.0	0.0	3.4	3.4	2.2	0.0

Table C-1. (continued)

May 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	40.5	46.7	4.4	17.4	34.8	43.3	45.6	13.3
31-60	20.2	21.1	22.0	16.3	38.2	32.2	10.0	43:3
61-90	4.8	10.0	27.5	9.3	10.1	3.3	11.1	21.1
91-120	4.8	8.9	4.4	2.3	1.1	4.4	7.8	3.3
121-150	0.0	4.4	20.9	3.5	0.0	3.3	16.7	0.0
151-180	4.8	2.2	12.1	1.2	0.0	1.1	6.7	8.9
181-210	1.2	0.0	3.3	0.0	0.0	3.3	0.0	2.2
211-240	2.4	2.2	1.1	2.3	0.0	3.3	0.0	2.2
241-270	0.0	0.0	2.2	8.1	1.1	0.0	1.1	2.2
271-300	1.2	0.0	0.0	19.8	0.0	0.0	0.0	1.1
301-330	6.0	0.0	2.2	5.8	6.7	4.4	0.0	1.1
331-359	14.3	4.4	0.0	14.0	7.9	1.1	1.1	1.1

16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	6.6	35.8	5.2	9.8	36.1	17.5	29.2	8.3
31-60	37.4	24.7	69.8	13.4	39.2	28.9	16.7	12.5
61-90	40.7	3.7	24.0	37.8	11.3	4.1	28.1	9.4
91-120	6.6	7.4	1.0	22.0	3.1	4.1	16.7	3.1
121-150	2.2	3.7	0.0	6.1	2.1	3.1	1.0	5.2
151-180	0.0	12.3	0.0	2.4	2.1	2.1	2.1	13.5
181-210	1.1	8.1	0.0	3.7	0.0	12.4	4.2	2.1
211-240	1.1	2.5	0.0	0.0	1.0	4.1	1.0	27.0
241-270	1.1	1.2	0.0	1.2	1.0	12.4	1.0	16.7
271-300	1.1	0.0	0.0	2.4	3.1	8.3	0.0	0.0
301-330	1.1	0.0	0.0	1.2	0.0	2.1	0.0	1.0
331-359	1.1	0.0	0.0	0.0	1.0	1.0	0.0	1.0

June 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	0.0	33.0	8.2	7.3	25.9	8.5	10.0	16.9
31-60	4.9	47.7	7.1	3.7	21.2	6.1	2.2	16.9
61-90	33.3	2.3	15.3	1.2	12.9	20.7	10.0	16.9
91-120	12.3	0.0	9.4	2.4	5.9	2.4	0.0	7.9
121-150	23.5	1.1	11.8	3.7	7.1	0.0	6.7	9.0
151-180	12.3	4.5	17.6	26.8	14.1	6.1	22.2	14.6
181-210	1.2	1.1	7.1	18.3	5.9	8.5	17.8	6.7
211-240	2.5	0.0	16.5	13.4	3.5	15.9	11.1	4.5
241-270	3.7	5.7	2.4	13.4	2.4	14.6	8.9	1.1
271-300	3.7	1.1	0.0	4.9	0.0	2.4	4.4	0.0
301-330	1.2	2.3	0.0	2.4	1.2	12.2	2.2	0.0
331-359	1.2	1.1	4.7	2.4	0.0	2.4	3.3	5.6

Table C-1. (continued)

June 16-30

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	1.1	30.0	4.5	2.2	12.6	0.0	40.0	20.0
31-60	33.3	8.6	10.1	15.7	6.9	6.0	20.0	5.6
61-90	43.3	4.3	41.6	38.2	11.5	18.1	5.6	16.7
91-120	14.4	8.6	13.5	22.5	6.9	18.1	1.1	10.0
121-150	4.4	8.6	7.9	0.0	9.2	37.4	1.1	2.2
151-180	0.0	7.1	13.5	13.5	18.4	12.1	0.0	14.4
181-210	1.1	1.4	9.0	5.6	20.7	3.6	3.3	8.9
211-240	0.0	5.7	0.0	1.1	5.8	1.2	5.6	7.8
241-270	0.0	14.3	0.0	1.1	2.3	2.4	10.0	1.1
271-300	0.0	4.3	0.0	0.0	5.8	0.0	1.1	4.4
301-330	1.1	2.9	0.0	0.0	0.0	1.2	6.7	5.6
331-359	1.1	4.3	0.0	0.0	0.0	0.0	5.6	3.3
July 1-15								
0-30	5.7	8.9	5.6	1.1	22.5	4.7	15.7	3.3
31-60	33.0	38.2	4.4	21.6	34.8	16.5	19.1	42.2
61-90	21.6	29.2	27.8	69.3	33.7	24.7	21.4	52.2
91-120	4.5	6.7	11.1	6.8	4.5	15.3	19.1	1.1
121-150	4.5	0.0	12.2	1.1	2.3	20.0	11.2	0.0
151-180	2.3	6.7	10.0	0.0	2.3	10.6	6.7	1.1
181-210	5.7	5.6	6.7	0.0	0.0	5.9	1.1	0.0
211-240	12.5	2.2	12.2	0.0	0.0	0.0	1.1	0.0
241-270	8.0	1.1	4.4	0.0	0.0	0.0	1.1	0.0
271-300	1.1	1.1	4.4	0.0	0.0	0.0	0.0	0.0
301-330	1.1	0.0	1.1	0.0	0.0	1.2	1.1	0.0
331-359	0.0	0.0	0.0	0.0	0.0	1.2	2.3	0.0
16-31								
0-30	5.2	2.2	5.2	1.0	3.1	8.9	13.5	20.8
31-60	29.9	30.4	42.7	18.8	3.1	25.6	36.5	49.0
61-90	48.5	27.2	37.5	63.5	7.3	40.0	21.9	28.1
91-120	13.4	28.3	7.3	12.5	66.7	8.9	10.4	2.1
121-150	3.1	6.5	5.2	4.2	22.9	1.1	3.1	0.0
151-180	0.0	3.2	2.1	0.0	0.0	2.2	8.3	0.0
181-210	0.0	1.1	0.0	0.0	0.0	2.2	1.0	0.0
211-240	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
241-270	0.0	0.0	0.0	0.0	0.0	2.2	1.0	0.0
271-300	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0
301-330	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
331-359	0.0	0.0	0.0	0.0	0.0	3.3	3.1	0.0

Table C-1. (continued)

August 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	2.3	1.1	5.7	3.6	1.1	1.1	0.0	0.0
31-60	25.0	29.2	43.2	46.4	11.1	21.4	2.2	25.6
61-90	48.9	47.2	23.9	28.6	31.1	69.7	34.4	37.8
91-120	20.1	21.3	12.5	14.3	30.0	6.7	10.0	5.6
121-150	2.3	1.1	8.0	4.8	16.7	0.0	10.0	3.3
151-180	1.1	0.0	0.0	2.4	10.0	1.1	24.4	7.8
181-210	0.0	0.0	0.0	0.0	0.0	0.0	11.1	11.1
211-240	0.0	0.0	0.0	0.0	0.0	0.0	4.4	7.8
241-270	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.1
271-300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
301-330	0.0	0.0	5.7	0.0	0.0	0.0	1.1	0.0
331-359	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0

16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	3.6	9.4	18.3	4.5	5.4	2.1	1.1	4.2
31-60	30.1	8.2	32.3	11.4	25.8	24.5	31.6	10.4
61-90	38.6	35.3	26.9	44.3	13.9	48.9	62.1	21.9
91-120	12.0	18.8	5.4	22.7	13.9	17.0	4.2	13.5
121-150	4.8	11.8	4.3	9.9	13.9	7.5	0.0	17.7
151-180	8.4	5.9	2.2	0.0	6.5	0.0	1.1	7.3
181-210	2.4	4.7	0.0	0.0	4.3	0.0	0.0	5.2
211-240	0.0	2.4	0.0	1.1	7.5	0.0	0.0	1.0
241-270	0.0	3.5	2.2	2.3	7.5	0.0	0.0	10.4
271-300	0.0	0.0	0.0	2.3	1.1	0.0	0.0	6.3
301-330	0.0	0.0	7.5	1.1	0.0	0.0	0.0	2.1
331-359	0.0	0.0	1.1	1.1	0.0	0.0	0.0	0.0

September 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	16.3	5.7	7.4	14.3	24.1	18.0	4.5	17.8
31-60	12.8	19.5	8.6	36.9	3.5	13.5	34.8	21.1
61-90	33.7	26.4	22.2	42.9	1.2	9.0	34.8	28.9
91-120	8.1	18.4	8.6	4.8	6.9	14.6	18.0	18.9
121-150	4.7	19.5	8.6	0.0	8.1	12.4	7.9	2.2
151-180	10.5	6.9	21.0	0.0	8.1	13.5	0.0	0.0
181-210	4.7	0.0	19.8	0.0	8.1	13.5	0.0	0.0
211-240	4.7	0.0	2.5	1.2	3.5	1.1	0.0	0.0
241-270	2.3	1.1	0.0	0.0	3.5	2.3	0.0	0.0
271-300	0.0	0.0	1.2	0.0	4.6	1.1	0.0	3.3
301-330	1.2	2.3	0.0	0.0	11.5	0.0	0.0	6.7
331-359	1.2	0.0	0.0	0.0	17.2	1.1	0.0	1.1

Table C-1. (continued)

September 16-30

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	28.2	13.5	20.0	16.3	42.4	35.7	17.1	25.6
31-60	38.8	50.6	32.2	29.1	23.5	15.5	17.1	28.9
61-90	9.4	30.3	27.8	26.7	7.1	4.8	11.4	20.0
91-120	5.9	4.4	11.1	17.4	5.9	1.2	3.4	11.1
121-150	0.0	1.1	6.7	1.2	1.2	2.4	8.0	4.4
151-180	5.9	0.0	0.0	2.3	0.0	3.6	15.9	5.6
181-210	0.0	0.0	2.2	0.0	5.9	8.3	2.3	2.2
211-240	2.4	0.0	0.0	0.0	2.4	3.6	9.1	2.2
241-270	5.9	0.0	0.0	2.3	3.5	14.3	13.6	0.0
271-300	2.4	0.0	0.0	1.2	1.2	2.4	2.3	0.0
301-330	1.2	0.0	0.0	2.3	2.4	3.6	0.0	0.0
331-359	0.0	0.0	0.0	1.2	5.9	4.8	0.0	0.0

October 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	7.7	10.0	7.9	4.5	20.2	18.9	26.1	73.0
31-60	14.3	28.9	6.7	29.5	47.2	12.2	29.6	21.3
61-90	26.4	32.2	28.1	22.7	21.4	20.0	14.8	5.6
91-120	19.8	13.3	14.6	12.5	7.9	35.6	4.6	0.0
121-150	6.6	12.2	16.9	15.9	0.0	11.1	3.4	0.0
151-180	2.2	2.2	6.7	5.7	0.0	2.2	1.1	0.0
181-210	0.0	1.1	3.4	2.3	0.0	0.0	0.0	0.0
211-240	7.7	0.0	3.4	1.1	0.0	0.0	4.6	0.0
241-270	7.7	0.0	10.1	2.3	0.0	0.0	3.4	0.0
271-300	3.3	0.0	2.2	1.1	0.0	0.0	2.3	0.0
301-330	3.3	0.0	0.0	1.1	1.1	0.0	8.0	0.0
331-359	1.1	0.0	0.0	1.1	2.3	0.0	2.3	0.0

16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	38.9	27.4	12.5	4.2	13.0	24.2	22.0	23.9
31-60	36.8	31.6	20.8	37.9	37.0	16.8	22.0	32.3
61-90	5.3	4.2	33.3	31.6	26.1	14.7	9.9	13.5
91-120	2.1	5.3	12.5	7.4	13.0	6.3	14.3	4.2
121-150	5.2	0.0	15.6	8.4	2.2	2.1	4.4	0.0
151-180	8.4	3.2	31.2	7.4	0.0	8.4	6.6	1.0
181-210	1.1	3.2	0.0	1.1	0.0	3.2	8.8	2.1
211-240	0.0	2.1	2.1	2.1	0.0	7.4	7.7	2.1
241-270	1.1	4.2	0.0	0.0	0.0	2.1	2.2	11.5
271-300	0.0	5.3	0.0	0.0	0.0	2.1	1.1	6.3
301-330	1.1	8.4	0.0	0.0	1.1	7.4	1.1	2.1
331-359	1.1	5.3	0.0	0.0	7.6	5.3	0.0	1.0

Table C-1. (continued)

November 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	20.5	8.0	17.4	10.0	34.8	44.2	11.1	12.2
31-60	19.3	12.6	12.8	21.1	11.2	11.6	25.6	13.3
61-90	17.0	26.4	11.6	22.2	15.7	10.5	21.1	12.2
91-120	18.2	13.8	16.3	18.9	10.0	1.2	15.6	10.0
121-150	5.7	3.4	9.3	7.8	2.2	0.0	17.8	1.1
151-180	6.8	8.0	2.3	8.9	5.6	1.2	0.0	4.4
181-210	8.0	4.6	9.3	4.4	0.0	1.2	0.0	0.0
211-240	1.1	6.9	8.1	5.6	1.1	3.5	0.0	4.4
241-270	0.0	1.1	2.3	0.0	1.1	10.5	0.0	7.8
271-300	1.1	0.0	5.8	0.0	1.1	10.5	0.0	10.0
301-330	2.3	6.9	3.5	1.1	13.5	1.2	1.1	16.7
331-360	1.1	8.0	1.2	0.0	3.4	4.7	0.0	6.7

16-30

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	5.6	11.1	36.8	6.7	50.6	22.2	6.7	28.9
31-60	7.8	33.3	13.8	5.6	20.0	7.8	10.0	7.8
61-90	36.7	32.2	8.0	3.4	3.5	3.3	23.3	8.9
91-120	30.0	6.7	5.7	2.2	2.4	13.3	10.0	16.7
121-150	5.6	1.1	0.0	0.0	1.2	3.3	3.3	4.4
151-180	5.6	1.1	1.1	2.2	2.4	3.3	6.7	7.8
181-210	4.4	6.7	6.9	18.0	1.2	4.4	14.4	4.4
211-240	2.2	6.7	8.0	10.1	0.0	5.6	2.2	4.4
241-270	1.1	1.1	10.3	13.5	1.2	10.0	11.1	5.6
271-300	1.1	0.0	3.4	22.5	0.0	17.8	5.6	1.1
301-330	0.0	0.0	2.3	10.1	9.4	7.8	4.4	4.3
331-359	0.0	0.0	3.4	5.6	8.2	1.1	2.2	3.2

December 1-15

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	13.1	8.9	16.1	11.5	5.8	24.4	21.8	23.4
31-60	3.6	3.3	6.9	11.5	19.5	1.1	25.3	6.4
61-90	13.1	3.3	2.3	4.6	18.4	3.3	13.8	30.1
91-120	1.2	4.4	1.1	8.0	10.3	4.4	4.6	21.3
121-150	2.4	3.3	3.4	8.0	13.8	2.2	1.2	4.3
151-180	3.6	3.3	8.0	18.4	13.8	7.8	1.2	1.1
181-210	16.7	10.0	6.9	5.7	4.6	16.7	2.3	0.0
211-240	20.2	16.7	13.8	5.7	4.6	17.8	4.6	0.0
241-270	8.3	15.6	5.7	10.3	0.0	4.4	11.5	4.3
271-300	4.8	11.1	8.0	11.5	4.6	3.3	2.3	1.1
301-330	13.1	13.3	25.3	3.4	4.6	10.0	8.1	4.3
331-359	0.0	6.7	2.3	1.1	0.0	4.4	3.5	3.2

Table C-1. (continued)

December 16-31

Direction	1961	1962	1963	1964	1965	1966	1967	1968
0-30	8.5	10.4	9.6	0.0	7.5	5.3	2.2	14.3
31-60	2.1	2.1	3.2	0.0	0.0	4.3	5.4	12.1
61-90	4.3	6.3	1.1	0.0	5.3	5.3	0.0	12.1
91-120	0.0	3.1	1.1	0.0	5.3	9.6	1.1	6.6
121-150	4.3	3.1	2.1	3.5	19.2	11.7	2.2	7.7
151-180	7.4	5.2	1.1	8.2	6.4	20.2	6.5	4.4
181-210	14.9	6.3	9.6	15.3	5.3	21.3	8.6	5.5
211-240	26.6	12.5	17.0	21.2	4.3	5.3	8.6	6.6
241-270	21.3	20.8	24.5	24.7	16.0	3.2	21.5	5.5
271-300	6.4	15.6	13.8	29.4	16.0	3.2	22.6	8.8
301-330	2.1	8.3	14.9	8.2	10.6	7.5	10.8	13.2
331-359	2.1	6.3	2.1	1.2	4.3	3.2	10.8	3.3

Table C-2. Average semi-monthly wind speed in Beaufort Scale (numbers in parentheses are range) at Kure Atoll, 1961-68.*

	January		February		March		April		May		June	
1961	-	-	-	-	-	2.8 (0-6)	2.9 (0-6)	2.2 (1-4)	2.6 (0-5)	2.6 (0-5)	2.1 (0-3)	2.8 (1-4)
1962	3.5 (0-7)	3.1 (0-7)	2.5 (0-6)	2.7 (1-5)	3.3 (0-6)	3.3 (0-8)	3.3 (1-6)	3.4 (0-6)	2.9 (1-4)	2.4 (0-6)	3.4 (0-5)	1.6 (0-4)
1963	3.6 (1-6)	3.6 (0-7)	4.0 (1-6)	3.2 (0-5)	2.3 (0-4)	3.5 (1-6)	2.7 (0-6)	3.3 (0-5)	2.7 (1-4)	3.2 (1-5)	2.2 (0-4)	2.6 (0-4)
1964	2.5 (0-5)	2.4 (0-5)	2.6 (0-5)	2.8 (0-7)	2.8 (0-6)	3.7 (0-6)	3.3 (1-5)	2.9 (0-5)	1.9 (0-4)	1.5 (0-5)	1.8 (0-5)	2.0 (1-4)
1965	3.2 (0-6)	2.7 (0-5)	2.3 (0-4)	3.6 (1-5)	3.2 (0-6)	3.1 (0-7)	2.8 (0-5)	2.7 (0-6)	2.6 (1-5)	2.6 (0-4)	1.9 (0-5)	2.1 (0-5)
1966	1.6 (0-5)	2.6 (0-7)	2.1 (0-5)	3.4 (0-7)	2.2 (0-5)	2.2 (0-4)	2.3 (0-5)	1.9 (0-5)	2.5 (1-5)	2.2 (1-4)	1.4 (0-5)	1.6 (0-6)
1967	1.9 (1-3)	1.9 (1-3)	2.3 (0-4)	1.6 (0-3)	2.3 (0-4)	1.9 (1-4)	2.6 (1-4)	1.9 (0-4)	2.0 (0-3)	2.2 (1-3)	1.8 (0-3)	2.5 (0-3)
1968	2.4 (0-4)	3.1 (1-5)	3.5 (1-6)	4.0 (2-7)	2.8 (1-5)	2.7 (1-5)	2.9 (1-5)	2.9 (1-5)	2.9 (1-5)	2.2 (1-3)	2.1 (1-4)	1.6 (1-4)

*Beaufort Scale: 0 = 1 knot, 1 = 1-3 knots, 2 = 4-7 knots, 3 = 8-12 knots, 4 = 13-18 knots, 5 = 19-24 knots, 6 = 25-31 knots, 7 = 32-38 knots, 8 = 39-46 knots

Table C-2. (continued)

	July		August		September		October		November		December	
1961	1.8 (0-3)	2.6 (0-6)	2.6 (0-5)	2.0 (0-5)	2.3 (0-5)	2.4 (0-5)	2.6 (1-5)	3.6 (1-6)	2.4 (0-5)	2.9 (1-5)	2.9 (0-6)	3.7 (0-5)
1962	3.0 (1-7)	2.6 (0-6)	2.8 (1-5)	1.6 (0-5)	2.1 (0-4)	2.3 (0-8)	2.9 (1-5)	3.0 (0-5)	2.2 (0-5)	3.0 (1-5)	3.6 (0-7)	2.6 (0-5)
1963	2.7 (1-4)	3.4 (1-5)	3.3 (1-8)	1.9 (0-6)	2.0 (0-6)	3.0 (1-7)	2.7 (1-6)	3.5 (1-6)	2.8 (0-6)	3.0 (0-7)	3.1 (0-6)	3.2 (0-6)
1964	2.9 (1-6)	2.8 (1-6)	3.0 (1-5)	2.1 (0-4)	2.5 (1-6)	2.3 (0-5)	2.0 (0-4)	3.2 (2-7)	3.1 (1-5)	2.9 (1-6)	2.7 (0-4)	4.0 (0-9)
1965	2.2 (0-4)	3.1 (1-6)	2.7 (1-4)	2.1 (0-4)	2.2 (0-4)	2.9 (0-6)	1.8 (0-5)	2.2 (0-5)	2.6 (0-4)	3.0 (0-5)	2.0 (0-8)	2.2 (0-5)
1966	1.9 (0-6)	2.4 (1-5)	2.8 (0-5)	2.3 (1-5)	2.3 (0-5)	2.0 (0-8)	3.0 (1-6)	2.1 (0-4)	2.3 (0-5)	2.2 (0-4)	2.2 (0-8)	2.0 (1-4)
1967	1.8 (0-3)	2.0 (0-3)	2.1 (0-3)	2.2 (1-3)	2.2 (0-3)	1.7 (0-4)	1.5 (0-3)	1.6 (0-3)	2.1 (1-5)	2.3 (1-4)	2.5 (0-5)	2.5 (0-5)
1968	2.5 (1-3)	2.7 (1-4)	2.4 (0-3)	2.3 (0-5)	2.2 (0-4)	2.3 (0-5)	3.1 (1-5)	2.2 (0-4)	2.6 (1-5)	2.9 (1-5)	3.6 (1-6)	3.0 (1-7)

Table C-3. Average semi-monthly maximum temperatures (numbers in parentheses are range) at Kure Atoll, 1961-68.

	January		February		March		April		May		June	
1961	-	-	-	-	-	71.9 (68-78)	69.1 (57-75)	74.5 (67-83)	73.5 (65-86)	81.6 (74-88)	84.2 (79-87)	82.8 (77-88)
1962	69.3 (59-73)	68.0 (63-72)	70.1 (62-76)	70.8 (66-74)	70.9 (66-74)	71.4 (62-76)	71.9 (65-76)	69.9 (64-75)	75.4 (74-79)	78.1 (69-84)	77.5 (75-83)	83.1 (74-87)
1963	69.9 (66-74)	69.6 (67-72)	68.5 (62-73)	67.1 (63-71)	72.1 (66-78)	69.6 (63-79)	69.7 (65-79)	74.4 (66-79)	79.3 (74-82)	80.4 (78-88)	81.7 (75-87)	83.5 (77-88)
1964	70.7 (64-74)	71.0 (65-74)	71.0 (64-75)	71.1 (65-74)	71.3 (65-78)	72.3 (67-76)	69.5 (64-78)	70.9 (66-76)	71.7 (65-78)	77.9 (70-80)	78.5 (70-84)	82.7 (79-85)
1965	66.5 (60-71)	65.8 (60-70)	68.7 (64-74)	70.9 (64-79)	69.4 (63-75)	71.6 (64-77)	72.2 (65-79)	70.9 (66-76)	72.2 (68-76)	72.9 (68-79)	80.5 (71-85)	79.9 (72-87)
1966	70.6 (67-74)	69.7 (60-74)	69.1 (63-72)	70.2 (63-74)	70.8 (65-74)	72.1 (67-75)	71.1 (65-75)	73.5 (67-78)	74.9 (72-78)	76.0 (72-78)	71.6 (76-87)	84.7 (81-87)
1967	72.0 (67-76)	70.9 (63-76)	67.9 (64-74)	70.5 (65-77)	68.1 (59-75)	71.4 (64-78)	74.5 (70-79)	75.0 (72-80)	75.5 (69-88)	79.1 (75-83)	77.7 (70-82)	81.8 (77-88)
1968	69.5 (64-75)	68.9 (65-70)	68.1 (61-70)	65.4 (61-70)	68.9 (60-77)	73.9 (67-78)	72.9 (68-79)	72.9 (65-79)	75.2 (67-80)	78.6 (72-85)	80.4 (70-88)	85.4 (76-91)

Table C-3. (continued)

	July		August		September		October		November		December	
1961	86.5 (80-89)	88.9 (87-91)	86.8 (82-93)	89.0 (84-92)	87.0 (82-91)	86.5 (76-90)	82.4 (75-89)	79.2 (70-85)	78.4 (75-84)	78.6 (76-82)	74.9 (67-81)	73.8 (69-77)
1962	83.6 (76-86)	84.9 (78-89)	87.6 (83-92)	86.7 (80-93)	86.9 (84-90)	88.7 (84-92)	85.9 (77-89)	80.1 (72-86)	79.3 (74-85)	79.3 (75-87)	73.5 (67-79)	69.8 (64-73)
1963	82.7 (76-86)	83.3 (76-86)	83.9 (76-87)	87.1 (80-90)	85.9 (84-89)	86.2 (78-90)	82.3 (74-86)	81.8 (77-85)	79.2 (74-84)	75.3 (69-78)	70.4 (62-76)	70.9 (65-78)
1964	83.5 (79-85)	82.5 (79-84)	82.6 (79-86)	85.2 (78-88)	85.1 (82-87)	83.1 (80-87)	84.8 (83-88)	80.2 (76-83)	76.9 (72-80)	73.5 (69-80)	72.4 (67-78)	65.6 (59-70)
1965	85.7 (85-87)	84.1 (75-89)	86.6 (84-88)	86.1 (84-89)	85.3 (78-99)	81.5 (77-86)	80.5 (73-85)	79.8 (72-83)	76.5 (70-81)	76.5 (70-81)	72.2 (66-78)	66.7 (62-75)
1966	86.1 (80-89)	86.1 (79-90)	86.3 (80-89)	87.1 (80-91)	84.1 (76-89)	84.3 (80-89)	81.0 (73-84)	80.3 (75-86)	75.0 (68-80)	74.1 (70-80)	71.2 (68-74)	72.6 (69-75)
1967	82.9 (77-89)	83.7 (79-88)	84.3 (80-87)	85.8 (81-89)	86.7 (83-90)	85.0 (80-89)	83.6 (80-86)	84.1 (76-88)	81.2 (75-86)	78.2 (75-86)	73.6 (65-80)	70.1 (63-74)
1968	91.3 (87-93)	90.9 (89-93)	91.1 (87-96)	86.1 (80-93)	90.6 (87-94)	84.7 (75-93)	81.6 (76-91)	84.6 (82-95)	78.6 (68-87)	73.7 (67-81)	73.0 (68-76)	69.1 (64-73)

Table C-4. Average semi-monthly minimum temperatures (numbers in parentheses are range) at Kure Atoll, 1961-68.

	January		February		March		April		May		June	
1961	-	-	-	-	-	62.0 (52-66)	56.9 (52-67)	61.7 (52-64)	61.7 (58-65)	66.9 (63-70)	72.3 (67-76)	72.8 (70-75)
1962	62.4 (56-68)	60.2 (52-64)	60.3 (57-65)	61.9 (57-67)	63.5 (59-67)	62.0 (55-65)	63.3 (57-69)	62.6 (55-69)	63.9 (61-66)	66.2 (60-74)	67.2 (64-71)	71.0 (68-74)
1963	64.7 (60-69)	63.4 (60-67)	61.9 (59-65)	60.8 (57-65)	63.3 (59-67)	62.3 (56-68)	51.5 (59-64)	63.7 (59-70)	68.3 (64-73)	69.1 (67-72)	72.9 (70-75)	73.5 (72-77)
1964	62.4 (57-68)	65.1 (61-69)	63.1 (50-69)	62.2 (55-70)	62.5 (55-70)	64.1 (60-68)	59.6 (56-63)	61.5 (57-65)	61.1 (59-66)	65.6 (60-70)	63.8 (52-72)	72.1 (70-73)
1965	60.7 (56-66)	58.3 (39-64)	60.5 (55-66)	62.2 (50-69)	61.7 (56-67)	63.1 (60-67)	60.4 (45-66)	58.5 (47-66)	62.3 (58-64)	61.1 (58-63)	68.3 (63-73)	71.6 (67-74)
1966	62.1 (57-68)	61.9 (50-69)	60.7 (59-65)	60.8 (57-65)	60.8 (50-67)	62.3 (55-68)	59.9 (56-68)	62.6 (57-66)	64.7 (62-68)	66.7 (64-69)	68.6 (62-73)	73.5 (69-77)
1967	64.7 (59-69)	62.3 (53-68)	58.7 (54-64)	59.8 (53-66)	58.9 (53-63)	59.9 (55-64)	64.9 (60-69)	64.3 (61-66)	64.1 (59-69)	67.2 (64-73)	70.7 (65-75)	70.6 (65-73)
1968	59.7 (48-66)	58.8 (50-63)	60.5 (49-64)	59.5 (55-64)	57.5 (51-64)	61.1 (57-65)	61.7 (59-65)	62.6 (60-65)	64.3 (58-70)	70.3 (66-74)	69.1 (63-74)	73.1 (65-78)

Table C-4. (continued)

	July		August		September		October		November		December	
1961	73.9 (68-76)	75.2 (73-76)	75.1 (74-77)	75.3 (72-78)	71.1 (72-79)	74.7 (72-77)	73.3 (64-76)	70.7 (62-74)	68.3 (64-73)	71.1 (67-74)	67.1 (57-70)	65.6 (58-71)
1962	74.7 (70-77)	73.9 (69-76)	75.5 (74-77)	74.5 (70-77)	75.5 (70-78)	75.0 (72-78)	75.3 (72-78)	70.8 (66-74)	69.7 (65-73)	69.8 (66-73)	66.3 (59-72)	63.0 (57-68)
1963	74.5 (68-77)	73.8 (71-76)	73.9 (70-77)	74.8 (69-78)	75.9 (72-78)	76.3 (72-79)	75.0 (70-79)	73.8 (70-78)	72.7 (65-77)	65.9 (56-73)	64.5 (57-72)	64.4 (54-72)
1964	72.5 (71-74)	71.1 (60-74)	71.5 (61-82)	73.0 (70-75)	73.1 (70-76)	71.9 (68-76)	70.6 (60-74)	69.8 (64-73)	68.2 (65-71)	64.1 (60-70)	62.0 (56-69)	57.6 (53-63)
1965	73.5 (71-75)	73.8 (71-75)	75.2 (74-77)	74.1 (71-77)	74.3 (70-77)	70.3 (67-74)	70.9 (67-94)	68.8 (62-72)	67.7 (65-71)	67.1 (60-70)	61.3 (54-68)	56.5 (52-62)
1966	75.6 (73-79)	76.3 (74-78)	75.2 (73-77)	75.4 (74-78)	74.1 (68-79)	72.7 (69-76)	72.5 (66-75)	69.9 (64-77)	65.9 (63-69)	66.7 (61-71)	63.1 (59-69)	65.3 (60-70)
1967	71.9 (67-75)	73.2 (69-75)	74.7 (72-78)	75.0 (73-76)	76.3 (75-78)	72.9 (68-77)	71.7 (68-75)	71.4 (68-75)	71.4 (66-75)	69.5 (62-74)	63.3 (52-72)	62.9 (55-68)
1968	74.8 (69-78)	74.6 (70-77)	77.3 (76-78)	76.4 (71-80)	76.4 (75-80)	74.4 (70-78)	72.3 (67-75)	72.1 (67-75)	66.3 (55-73)	65.5 (51-70)	67.9 (65-70)	61.3 (54-66)

Table C-5. Semi-monthly rainfall (in inches) at Midway Atoll, 1963-68.

	January		February		March		April		May		June	
1963	3.2	3.5	1.5	1.7	3.9	9.3	2.8	0.5	1.4	0.1	0.1	1.4
1964	1.2	3.5	1.8	0.5	6.8	2.4	1.9	0.2	3.0	0.1	1.3	0.9
1965	1.3	1.2	2.0	1.5	2.0	1.1	0.1	2.1	0.2	0.1	1.8	3.7
1966	0.8	1.6	0.5	0.4	1.1	0.6	0.8	0.1	1.3	1.2	0.1	0.7
1967	0.7	2.2	3.1	5.0	1.7	0.5	0.5	1.8	0.7	0.4	3.0	0.1
1968	2.7	3.6	3.9	0.6	0.1	0.1	1.0	0.1	0.7	1.8	1.7	0.8

	July		August		September		October		November		December	
1963	1.3	5.3	2.7	0.3	0.4	2.7	3.8	2.4	9.2	1.7	1.6	0.4
1964	0.7	1.9	0.8	0.4	0.3	0.8	1.4	4.7	7.0	2.1	1.7	3.9
1965	0.3	1.0	0.2	1.3	1.3	2.2	0.2	0.6	0.8	3.2	0.5	3.4
1966	0.3	1.9	0.8	0.9	4.4	0.1	7.4	1.3	1.4	1.3	0.9	0.5
1967	5.9	7.4	6.5	0.3	0.9	1.0	1.3	0.3	7.0	3.3	2.8	2.0
1968	0.3	1.6	0.5	6.7	3.1	2.3	0.9	0.5	1.1	2.8	6.0	11.9

SCIENTIFIC VISITS

Biological Surveys

Kure Atoll received minimal attention from biologists prior to POBSP studies. In the first half of this century only two detailed surveys were made--one in 1915 and another in 1923.

On 28 March 1915 Lt. W.H. Munter of the Coast Guard Cutter *Thetis* spent about 5 hours on Green Island. He recorded 9 avian and 2 mammalian species. From 16 to 22 April 1923 the *Tanager* Expedition, a joint venture of the Bureau of Biological Survey of the U.S. Department of Agriculture and the Bernice P. Bishop Museum, visited the atoll. Led by Dr. Alexander Wetmore, the expedition collected representatives of most biological groups. Most of the data except bird observations were subsequently published. Dr. Wetmore kindly permitted me to utilize his bird observations and publish those records here. Ten additional avian species were added to the Kure checklist.

An earlier expedition sent to the Northwestern Hawaiian Islands by the U.S. Bureau of Biological Survey was unable to land at Kure when it visited the atoll on 18 September 1918. However, Lt. John T. Diggs of the U.S.S. Hermes reported 5 avian species, including the first White Tern, flying around the ship.

It was not until 34 years after the Tanager Expedition that the atoll was again systematically surveyed. On 5 June 1957 Karl W. Kenyon and Dale W. Rice of the United States Fish and Wildlife Service (the successor to the Bureau of Biological Survey) spent about 9 hours ashore and made detailed bird and seal observations. One year later, on 9 May, Rice again visited the atoll, but restricted his activities to the beach. These men also made aerial surveys on 9 and 21 December 1956; 12 February, 14 May, 18 December 1957; and 14 April, 2 May, and 28 June 1958. No new avian species were recorded.

The next to last visit prior to the construction of the LORAN station was 3 to 8 October 1959. Chandler S. Robbins, Thomas C. Horn, Horace F. Clay, and a team of Navy personnel landed on Green Island to improve the habitat for breeding albatross. A series of 18 trails connecting the open central plain with the beach was bulldozed. During this period Clay collected vascular plants and Robbins estimated bird populations. This was the first of six trips that Robbins, of the United States Fish and Wildlife Service, made to Kure prior to POBSP studies. During each stay he estimated avian populations and banded a total of 3,445 birds (Robbins, 1966). Three additional avian species were recorded during these visits.

James Hunt, a member of the United States Coast Guard, banded 400 birds of 5 species in April and May 1961. He made no systematic observations.

The only other significant biological survey prior to the POBSP surveys was from 12 to 14 September 1961 when the Harold J. Coolidge expedition visited Kure. Plants and insects were collected and limited bird observations were made.

In the winter and spring of 1963 POBSP personnel visited the atoll four times but made systematic bird observations on only one visit. Full time POBSP operations began on 13 September 1963 and continued until 19 August 1965. Extended surveys were also made from 17 April to 6 October 1966, 4 May to 9 July 1967, and 26 May 1968 to 20 June 1969.

Robbins surveyed the atoll in February 1966 and 1967 when POBSP personnel were not present. His observations are listed under POBSP records.

During POBSP studies emphasis was placed on determining what avian species occurred, when they occurred, in what number, if and when they bred, and on studying the detailed breeding biology of selected species. To facilitate this work, 60,282 birds were individually marked with numbered aluminum bands, thus allowing us to follow the life history of individuals and trace their movements. It is this work that forms the major portion of this paper. Lesser emphasis was placed on studying mammals and plants.

Table BS-1 lists major biological surveys of Kure, Table BS-2 lists minor biological surveys, and Tables BS-3 and 4 list the POBSP survey team.

Other Scientific Visits

Hydrographic surveys were made by the U.S.S. *Lackawanna* in 1867, the U.S.S. *Tanager* in 1924, and the U.S.S. *Oglala* in 1936. These trips were discussed in the History Section. The *Lackawanna* survey produced Hydrographic Office Chart 4 which showed Green Island incorrectly as approximately rectangular in shape. The latter two surveys corrected this mistake as shown in the recent United States Coast and Geodetic Survey Chart 4177.

Geodetic markers were established on Green Island in June, October, November 1959 and during 1961 by the United States Hydrographic Office, United States Coast and Geodetic Survey, and the Army Map Service. I have no details of these visits.

A study of the marine geology of the atoll was conducted by T.S. Chamberlain, M.G. Gross, G.V. Keller, and J.I. Tracey, Jr., from 29 August to 7 September 1965. Results of this work were published by Gross, *et al*. (1969) and Keller (1969). Thomas F. Dana reported on the corals of Kure [Dana (1971)] as a result of his work at the atoll with Scripps Institution of Oceanography in September 1968 and with the POBSP in 1969.

KURE AVIFAUNA

Introduction

Prior to POBSP studies twenty-six avian species were recorded from Kure Atoll through the combined efforts of Munter (1915), Wetmore (ms.), Kenyon and Rice (1958), and Robbins (1966). These observers recorded fourteen of the fifteen breeding species, all six of the common non-breeding species, and six rare or accidental species. The POBSP recorded an additional forty species and one hybrid; all but one, the Sooty Storm Petrel,

Table BS-1. Major biological surveys of Kure Atoll.

Date of Survey	Personnel	Resultant Publications and Manuscripts
1915 March 28	_Thetis_: Lt. W.H. Munter	Munter (1915), Pilsbury (1917).
1923 April 16-22	_Tanager Expedition_: Alexander Wetmore Edward L. Caum David T. Fullaway Chapman Grant Ditlev Thaanum	Bryan, _et al_. (1926), Christophersen and Caum (1931), Edmondson _et al_. (1925), Fowler and Ball (1925), Wetmore (1925, ms.).
1957 June 5	_USFWS_:* Karl W. Kenyon Dale W. Rice	Kenyon and Rice (1958, 1959), Kenyon (ms.), Rice (1960a), Rice and Kenyon (1962).
1958 May 9	Dale W. Rice, USFWS	Kenyon (ms.), Rice and Kenyon (1962), Rice (1960a, b, pers. corr.).
1959 October 3-8	Chandler S. Robbins, USFWS Horace F. Clay, University of Hawaii Thomas C. Horn, USFWS	Clay (1960), Robbins (1966).
1960 March 28	Chandler S. Robbins, USFWS Cdr. Edward P. Wilson, U.S. Navy	Robbins (1966).
1961 January 19-21	Chandler S. Robbins, USFWS Cdr. Edward P. Wilson, U.S. Navy	Robbins (1966).

Table BS-1. (continued)

Date of Survey	Personnel	Resultant Publications and Manuscripts
1961 September 12-14	Harold S. Coolidge Expedition: George D. Bulter, Jr., University of Arizona; Edward C. Jestes, University of Hawaii; Charles H. Lamoureux, University of Hawaii; A. Starker Leopold, University of California; Miklos D.F. Udvardy, University of British Columbia; William Usinger, University of California; Martin J. Vitousek, University of Hawaii; Ronald L. Walker, Hawaii Fish and Game; Richard E. Warner, University of California; David Woodside, Hawaii Fish and Game	Bulter and Usinger (1963), Lamoureux (1961), Udvardy (1961), Udvardy and Warner (1964).
1962 February 2-4	USFWS: Chandler S. Robbins; Paul A. Stewart	Robbins (1966)
August 6-8	Chandler S. Robbins, USFWS	Robbins (1966)

Table BS-1. (continued)

Date of Survey		Personnel	Resultant Publications and Manuscripts
1963	February 3-7	USFWS: Chandler S. Robbins John Waters	Robbins (1966).
	May 8-10	POBSP:** Robert W. McFarlane Fred C. Sibley	This paper.
1963 1965	September 13 to August 19	Various POBSP personnel	Amerson (1968), Clapp and Woodward (1968), Fleet (ms.), Kepler (1967, 1969), Maa (1968), Sibley and McFarlane (1968), Steele (1967), Tsuda (1966), Wirtz (1968, ms.), this paper.
	November 12 to December 16	POBSP: T. James Lewis	This paper.
1966	January 16-18	POBSP: T. James Lewis Max C. Thompson	This paper.
	February 6-10	Chandler S. Robbins, USFWS Norman E. Holgersen	Robbins (ms.), this paper.
	April 17 to October 6	Various POBSP personnel	This paper.
1967	December 30 to January 5	POBSP: Lawrence N. Huber T. James Lewis	This paper.

Table BS-1. (continued)

Date of Survey		Personnel	Resultant Publications and Manuscripts
1967	February 9-12	USFWS: Chandler S. Robbins Van T. Harris	Robbins (ms.), this paper.
	March 26-30	POBSP: C. Douglas Hackman	This paper
	May 4 to July 9	POBSP: Walter Bulmer Paul W. Woodward	This paper.
1968	March 28-31	POBSP: Robert L. Pyle Roger B. Clapp	This paper.
1969	May 26 to June 20	Various POBSP personnel	This paper.

* United States Fish and Wildlife Service
** Pacific Ocean Biological Survey Program

Table BS-2. Minor biological surveys of Kure Atoll.

Date of Survey		Personnel	Nature of Survey	Resultant Publications and Manuscripts
1918	September 18	USS *Hermes* Lt. John T. Diggs	Offshore observations	RG 45, National Archives Report of Commanding Officer USS *Hermes* to Commandant 14th Naval Dist.
1956	December 9	USFWS*	Aerial	Aldrich *et al.* (ms.), Kenyon and Rice (1959).
	December 21	USFWS	Aerial	Kenyon and Rice (1958, 1959), Kenyon (ms.).
1957	February 12	USFWS	Aerial	Kenyon and Rice (1959), Kenyon (ms.).
	May 14	USFWS	Aerial	Kenyon and Rice (1959), Kenyon (ms.).
	December 18	USFWS	Aerial	Rice (1960b), Kenyon (ms.).
1958	April 14	USFWS	Aerial	Rice (1960b), Kenyon (ms.).
	May 2	USFWS	Aerial	Rice (1960b), Kenyon (ms.).
	June 28	USFWS	Aerial	Rice (1960b), Kenyon (ms.).
1959	September 26-28	Chandler S. Robbins, USFWS	Offshore observations	Robbins (ms.).
1960	March 25	Chandler S. Robbins, USFWS	Aerial	Robbins (ms.).
1963	January 17	Chandler S. Robbins, USFWS	Banded Black-footed albatross	Robbins (ms.), this paper.

* United States Fish and Wildlife Service

Table BS-2. (continued)

Date of Survey		Personnel	Nature of Survey	Resultant Publications and Manuscripts
1963	January 27	Robert Klemm, University of Southern Illinois	Cursory survey	Fisher (1965).
	February 20	POBSP: Robert W. McFarlane William O. Wirtz, II	Cursory survey	No systematic observations.
	March 10	POBSP: A. Binion Amerson, Jr. Robert W. McFarlane Fred C. Sibley		Clapp and Woodward (1968). No systematic observations.
	June 30	POBSP: A. Binion Amerson, Jr. Robert W. McFarlane		No systematic observations.
	December 11	Harvey I. Fisher, University of Southern Illinois	Cursory survey	Fisher (1965).
1964	January 16	Carl W. Buchheister, President, National Audubon Society Ira N. Gabrielson, Wildlife Management Institute W. Michael Ord, Hawaii Audubon Society	Cursory survey	--

Table BS-2. (continued)

Date of Survey	Personnel	Nature of Survey	Resultant Publications and Manuscripts
1964 January 16	Charles Zirzow, U.S. Navy	Cursory survey	--
	Ross Leonard, U.S. Navy		
	Chandler S. Robbins, USFWS		
March 12-15	Chandler S. Robbins, USFWS		
March 15-20	Ronald L. Walker, Hawaii Fish and Game	Capture seals, help POBSP	--
April 7-9	David Woodside, Hawaii Fish and Game	Discuss Sooty Tern problem	
August 13-16	Charles H. Lamoureux, University of Hawaii	Plant survey	This paper.
September 8-10	James Kelly, Sea Life Park	Capture seals	--
September 14	John W. Beardsley, University of Hawaii	Cursory survey	Beardsley (1966).
	Eugene Kridler, USFWS		
	Robert Long, POBSP		
	Ronald L. Walker, Hawaii Fish and Game		

Table BS-2. (continued)

Date of Survey		Personnel	Nature of Survey	Resultant Publications and Manuscripts
1965	April 2	Stanley A. Cain, Assistant Secretary of the Interior	Cursory survey	Trip report, Assistant Secretary for Fish and Wildlife, Hawaii, March 31-April 11, 1965.
		Eugene Kridler, USFWS Chandler S. Robbins, USFWS		
1966	March 15-16	Chandler S. Robbins, USFWS	Band albatross	This paper.
	April 4	Ronald L. Walker, Nelson Rice, Hawaii Fish and Game	Cursory survey	--
1968	March 28	Karl W. Kenyon, USFWS	Count seals	--
		Ernest F. Kosaka, Hawaii Fish and Game		
1969	January 31-February 3	Harvey I. Fisher, University of Southern Illinois	Cursory survey	--
		Robert Klemm, Kansas State University		
	April 10-13	Ronald L. Walker, Hawaii Fish and Game	Seal survey	--

Table BS-3. Total man-days spent at Kure Atoll by POBSP personnel.

Personnel	Days
William O. Wirtz II	316
Robert R. Fleet	267
Paul W. Woodward	220
Vernon M. Kleen	150
Dennis L. Stadel	149
David A. Bratley	106
Cameron B. Kepler	103
Thomas F. Dana	85
T. James Lewis	82
Paul G. DuMont	81
James P. Ludwig	80
Alan H. Anderson	70
George R. Wislocki	70
Robert L. Brownell	68
Robert A. Sundell	57
Roger B. Clapp	56
Robert L. DeLong	56
Ralph W. Schreiber	54
Norman N. Heryford	50
Robert S. Standen	49
Kenneth A. Amerman	44
Warren B. King	37
Richard L. Maze	36
Walter Bulmer	11
Robert L. Pyle	9
Lawrence N. Huber	6
Charles A. Ely	4
C. Douglas Hackman	4
Robert W. McFarlane	2
Fred C. Sibley	2
Max C. Thompson	2
A. Binion Amerson, Jr.	1
Total Man-Days	2,327

Table BS-4. Man-days spent at Kure Atoll by POBSP personnel (listed by years).

Personnel	Dates	Days
1963		
James P. Ludwig	September 13-December 1	80
William O. Wirtz II	February 20; September 20-November 27	69
Kenneth A. Amerman	October 30-December 12	44
Roger B. Clapp	December 5-31	27
Warren B. King	December 26-31	6
Robert W. McFarlane	February 20; March 10; May 8-10; June 30	2
Fred C. Sibley	March 10; May 8-10	2
A. Binion Amerson, Jr.	March 10; June 30	1
	Subtotal	231
1964		
Robert R. Fleet	January 26-June 7; October 11-December 23	209
William O. Wirtz II	February 23-May 4; July 23-November 25	197
Dennis R. Stadel	July 12-October 4; December 10-31	107
Paul G. DuMont	August 6-October 25	81
George S. Wislocki	May 1-July 9	70
Robert A. Sundell	June 7-August 2	57
Cameron B. Kepler	October 26-November 29; December 23-31	44
Warren B. King	January 1-31	31
Roger B. Clapp	January 1-26	26
Charles A. Ely	November 8-12	4
	Subtotal	826
1965		
David A. Bratley	May 6-August 19	106
Alan H. Anderson	February 15-April 25	70
Cameron B. Kepler	January 1-February 28	59
Robert R. Fleet	March 4-April 30	58
William O. Wirtz II	March 28-May 16	50
Norman N. Heryford	April 22-June 10	50
Robert S. Standen	January 24-April 2	49
Dennis R. Stadel	January 1-February 11	42
T. James Lewis	November 12-December 16	35
	Subtotal	519

Table BS-4. (continued)

Personnel	Dates	Days
1966		
Paul W. Woodward	April 17-July 3	77
Ralph W. Schreiber	August 14-October 6	54
T. James Lewis	January 16-18; July 14-August 21; September 18-22; December 30-31	46
Richard L. Maze	June 30-August 4	36
Max C. Thompson	January 16-18	2
Lawrence N. Huber	December 30-31	2
	Subtotal	217
1967		
Paul W. Woodward	May 4-July 9	66
Walter Bulmer	April 30-May 11	11
Lawrence N. Huber	January 1-5	4
C. Douglas Hackman	March 26-30	4
T. James Lewis	January 1	1
	Subtotal	86
1968		
Paul W. Woodward	May 26-August 11	77
Robert L. Brownell	July 28-October 4	68
Robert R. DeLong	October 18-December 13	56
Vernon M. Kleen	December 10-31	21
Robert L. Pyle	March 28-31	3
Roger B. Clapp	March 28-31	3
	Subtotal	228
1969		
Vernon M. Kleen	January 1-March 28; April 10-May 23	129
Thomas F. Dana	February 10-April 4; May 19-June 20	85
Robert L. Pyle	April 18-24	6
	Subtotal	220
	Total Man-Days:	2,327

were rare or accidental visitors to the atoll. Clapp and Woodward (1968) summarized the records of thirty-four of these species. Since that paper was written, another five species were recorded and a previously unreported sighting of a Bulwer's Petrel was found. Therefore, by June 1969, sixty-six avian species and one hybrid were recorded from the atoll. These species fall into four categories: breeding, common non-breeding, rare visitors, and accidental visitors.

Breeding Species

Fourteen species definitely breed at the atoll and the Sooty Storm Petrel probably breeds. These species are classified according to their breeding seasons as follows:

Winter-Spring Breeders

Black-footed Albatross, *Diomedea nigripes*
Laysan Albatross, *Diomedea immutabilis*
Bonin Petrel, *Pterodroma h. hypoleuca*
Sooty Storm Petrel?, *Oceanodroma tristrami*

Winter-Summer Breeders

Red-tailed Tropicbird, *Phaëthon rubricauda*
Blue-faced Booby, *Sula dactylatra*
Red-footed Booby, *Sula sula*
Great Frigatebird, *Fregata minor*

Spring-Summer Breeders

Christmas Shearwater, *Puffinus nativitatus*
Brown Booby, *Sula leucogaster*
Sooty Tern, *Sterna fuscata*
Gray-backed Tern, *Sterna lunata*
Brown Noddy, *Anoüs stolidus*
White Tern, *Gygis alba*

Summer-Fall Breeders

Wedge-tailed Shearwater, *Puffinus pacificus*

Besides breeding on Northwestern Hawaiian Islands, the Black-footed Albatross breeds on Torishima, the Laysan Albatross breeds nowhere else, the Bonin Petrel breeds on the Bonin Islands, the Sooty Storm Petrel breeds on the Volcano Islands, and the other species breed commonly on islands throughout the central Pacific.

Common Non-breeding Species

The American Golden Plover (Pluvialis dominica), Ruddy Turnstone (Arenaria interpres), Bristle-thighed Curlew (Numenius tahitiensis), Wandering Tattler (Heteroscelus incanum), Sanderling (Crocethia alba), and Black Noddy (Anoüs tenuirostris) commonly visited the atoll. The Bristle-thighed Curlew and Wandering Tattler are Nearctic forms, while the other shorebird species breed in both the Palearctic and Nearctic regions. Black Noddies breed commonly on other Hawaiian Islands.

Rare Non-breeding Species

Seven species are regular visitors (more than five records) to the atoll in small numbers. The Sooty Shearwater (Puffinus griseus), which regularly washed up on the beaches, is a southern hemisphere species that migrates commonly through the central Pacific. The other six species, Sharp-tailed Sandpiper (Erolia acuminata), Herring Gull (Larus arsentatus), Short-eared Owl (Asio flammeus), Pintail (Anas acuta), Pectoral Sandpiper (Erdia melanotos) and Glaucous-winged Gull (Larus glaucescens) are northern migrants; the former three breed in Siberia and the others breed in the Palearctic and Nearctic regions.

Accidental Species

The remaining thirty-eight species were recorded less than five times. These species can be classified by origins as follows (number in parentheses is the number of records):

Breed on other Hawaiian Islands

Bulwer's Petrel, Bulweria bulwerii (1)
White-tailed Tropicbird, Phaëthon lepturus (1)
Black-crowned Night Heron, Nycticorax nycticorax (1)
House Sparrow, Passer domesticus (1)

Breed on Equatorial Islands in the Central Pacific

Lesser Frigatebird, Fregata ariel (2)

Occur at Sea in the Area but Only Rarely or Not at All on Islands

Northern Fulmar*, Fulmarus glacialis (4)
Kermadec Petrel**, Pterodroma neglecta (1)
Murphy's Petrel**, Pterodroma ultima (1)

Leach's Storm Petrel*, Oceanodroma leucorhoa (2)
Red Phalarope*, Phalaropus fulicarius (2)
Black-legged Kittiwake*, Rissa tridactyla (2)
Arctic Tern*, Sterna paradisea (1)

Northern Vagrants

Emperor Goose*, Philacte canagica (1)
European Widgeon***, Mareca penelope (2)
Tufted Duck***, Aythya fuligula (3)
Bufflehead****, Bucephala albeola (1)
Peregrine Falcon*, Falco peregrinus (1)
Dotterel***, Eudromias morinellus (1)
Black-bellied Plover*, Squatarola squatarola (3)
Pintail Snipe***, Capella stenura (1)
Common Snipe****, Capella gallinago (1)
Wood Sandpiper***, Tringa glareola (2)
Lesser Yellowlegs****, Totanus flavipes (1)
Dunlin***, Erolia alpina (2)
Long-billed Dowitcher*, Limnodromus scolopaceus (1)
Western Sandpiper****, Ereunetes mauri (1)
Bar-tailed Godwit*, Limosa lapponica (1)
Ruff***, Philomachus pugnax (1)
Ring-billed Gull****, Larus delawarensis (1)
Slaty-backed Gull****, Larus schistisagus (1)
Glaucous Gull*, Larus hyperboreus
Black Tern*, Chlidonias niger (1)
Horned Puffin*, Fratercula corniculata (5)
Skylark***, Alauda arvensis (1)
Barn Swallow***, Hirundo rustica (1)
Water Pipit***, Anthus spinoletta (1)
Red-throated Pipit***, Anthus cervinus (1)
Snow Bunting****, Plectrophenax nivalis (1)

Populations

The term "island population" can be defined in at least five ways: (1) maximum number of birds on the island at any one time during a given period, (2) maximum number of birds using the island during a given period, (3) maximum number of birds using the island during the breeding season or year,

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* Breeds in Palearctic and Nearctic Regions
** Breeds in Southern Hemisphere
*** Breeds in Palearctic Region
**** Breeds in Nearctic Region

(4) maximum number of birds breeding on the island during a breeding season, and (5) the mean or median number of birds using the island during a given period or a breeding season. In the following species accounts, POBSP estimates in the tables usually have the first meaning and the given period is of approximately two weeks duration. Where possible, island populations are discussed from the point of view of the other meanings in the written accounts. The latter estimates are more sophisticated than the first type because they involve handling a large percentage of the total species population to determine the actual number of birds using the island or to determine turnover rates for calculations of the size of the total pupulation.

Although the basic conditions (e.g., no emigration, no immigration, no mortality) for using the Lincoln Index were lacking, in some species this index was used to estimate population size. In no way is this meant to be an accurate calculation; it was used under certain circumstances where other data were lacking to indicate, in a general way, the size of the population. Banding totals and the number of previously banded birds handled each year are another index of population size. These totals are included in each species account and the reader is referred to them for an indication of the minimum number of birds that used the island during POBSP studies.

Table POP-1 summarizes basic population data for the common species occurring at the atoll, and Table POP-2 compares the size of the breeding populations from 1964 to 1969.

For comparison, the size of the breeding populations are the best data since they were usually actual counts or based on counts. Breeding populations varied considerably in size from year to year (see Red-footed Boobies and Sooty Terns), but there was no indication that decreases resulted from excessive adult mortality for in most cases the population increased the year after it had decreased. Generally it appeared that the population size of breeding species remained relatively constant during POBSP studies.

Apparently there was a direct correlation between the timing of the yearly breeding cycle and the size of the breeding population. In years when a species bred later than usual, the population decreased in size. Table POP-3 shows the species in which this relationship was noted and the size of the decrease. In all but one case the population increased the year after it decreased.

Table POP-1. Maximum and minimum population estimates of avian species occurring commonly at Kure Atoll, 1964-69.*

Species	Maximum Population Estimate	Minimum Population Estimate	Maximum Breeding Population Estimate	Minimum Breeding Population Estimate
Black-footed Albatross	1,000	0	662	400
Laysan Albatross	7,000	0	3,200	1,402
Bonin Petrel	2,500	0	1,000	-
Wedge-tailed Shearwater	6,230	0	2,000	1,000
Christmas Shearwater	150	0	24	6
Sooty Storm Petrel	10	0	-	-
Red-tailed Tropicbird	2,500	5	2,610	1,400
Blue-faced Booby	275	50	140	78
Brown Booby	150	15	90	76
Red-footed Booby	1,058	137	958	348
Great Frigatebird	1,500	15	800	240
American Golden Plover	137	3	-	-
Ruddy Turnstone	150	2	-	-
Bristle-thighed Curlew	12	0	-	-
Wandering Tattler	14	0	-	-
Sanderling	13	0	-	-
Sooty Tern	25,000	0	20,700	4,000
Gray-backed Tern	90	0	78	40
Brown Noddy	1,650	0	1,568	800
Black Noddy	2,000	0	-	-
White Tern	55	0	12	2

* First two columns include estimates made throughout the year. Last two columns include maxima and minima at the height of the breeding season.

Table POP-2. Size of breeding populations on Green Island, Kure Atoll, 1964-69.*

Species	1964	1965	1966	1967	1968	1969
Black-footed Albatross	470	542 (+15.3)	400 (-35.5)	400	406 (+1.5)	662 (+38.7)
Laysan Albatross	3,200	1,682 (-47.4)	1,800 (+7.0)	2,100 (+16.7)	1,402 (-33.2)	2,000 (+42.7)
Bonin Petrel	?	1,000	?	?	?	600

Table POP-2. (continued)

Species	1964	1965	1966	1967	1968	1969
Wedge-tailed Shearwater	2,000	2,000	1,700 (-15.0)	1,000 (-41.2)	1,500 (+50.0)	?
Christmas Shearwater	6	6	6	8 (+33.3)	6 (+25.0)	24 (+300.0)
Sooty Storm Petrel	?	?	?	?	?	?
Red-tailed Tropicbird	1,400	2,000 (+42.9)	2,100 (+5.0)	2,610 (+24.3)	1,880 (-28.0)	?
Blue-faced Booby	140	120 (-14.3)	78 (-35.0)	112 (+43.6)	108 (-3.6)	103 (-4.6)
Brown Booby	86	90 (+4.7)	82 (-8.9)	76 (-7.3)	80 (+5.3)	76 (-5.0)
Red-footed Booby	400	482 (+20.5)	348 (-27.8)	858 (+146.6)	594 (-30.8)	780 (+31.3)
Great Frigatebird	800	532 (-33.5)	400 (-24.8)	512 (+28.0)	240 (-53.1)	380 (+58.3)
Sooty Tern	4,000	7,000 (+75.0)	14,986 (+114.1)	16,530 (+10.3)	5,700 (-65.5)	20,700 (+263.2)
Gray-backed Tern	50	50	40 (-20.0)	78 (+95.0)	52 (-33.3)	40 (-23.1)
Brown Noddy	1,000	1,056 (+5.6)	800 (-24.4)	1,568 (+96.0)	978 (-37.6)	?
White Tern	8	6 (-25.0)	4 (-33.3)	10 (+150.0)	12 (+20.0)	2 (-83.3)

* First number is the total number of birds breeding; number in parentheses is the percent of change from the previous year.

Table POP-3. Relationship of lateness of breeding cycles and the size of the breeding population of four species on Green Island, Kure Atoll.

Species	Year of Decrease	Percent Decrease	Difference in timing of breeding from previous year
Blue-faced Booby	1966	35.0	Egg laying began 1 month later; peak egg laying began 1 month later.

Table POP-3. (continued)

Species	Year of Decrease	Percent Decrease	Difference in timing of breeding from previous year
Red-footed Booby	1966	27.8	Egg laying began 2 months later; peak egg laying began 1 week later.
Sooty Tern	1968	65.5	Egg laying began 10 days later; peak egg laying began 2 weeks later.
Brown Noddy	1968	37.6	Egg laying began 18 days later; peak egg laying began 1-1/2 months later.

Although the reasons for this phenomenon are unknown, two possibilities seem worthy of mention. If we assume that the lateness of breeding was caused by a food shortage, then it is likely that when conditions became favorable for breeding, i.e., when more food became available, the food supply was still insufficient to support the number of birds that had bred the previous year. In this case both the lateness of breeding and the population decrease were independent reactions to a single critical factor--food shortage.

A second possibility is the internal physiological rhythm of the breeders. This assumes that the annual rhythm is well-defined in each species so that at a certain time each year the birds reach the proper hormonal level for breeding. If breeding is delayed by such factors as food shortage, it is possible that the birds enter a refactory period which prevents them from breeding when environmental conditions become favorable again. Unfortunately, data are lacking to support either hypothesis or to elucidate the problem further.

Since man greatly altered the habitat on Green Island (see History Section), it is worthwhile to consider the changes in population size of the common species after 1959. Before 1960 observations were made sporadically and most early observers spent little time on the island. In contrast, POBSP observations were generally so intensive and extensive that a detailed set of early observations would be necessary to determine accurately the degree of change. However, the data are sufficient to indicate probable changes (Table POP-4).

Both Laysan Albatross and Sooty Terns, open-area breeders, definitely increased, but it is not certain that the habitat alteration was the major reason for this increase. Another factor may have been human disturbance of these species at Midway Atoll during the late 1950's and early 1960's (Robbins, 1966). These species were harassed to prevent them from breeding near the runways where they were potential

hazards to aircraft. Perhaps this harassment was sufficient to move the birds to Kure Atoll, where they bred when suitable habitat became available.

Table POP-4. Probable changes in population size of common avian species at Kure Atoll after 1959.

<u>Species in which there was an increase or apparent increase</u>

Laysan Albatross
Sooty Storm Petrel
Red-tailed Tropicbird
Sooty Tern
Brown Noddy

<u>Species in which there was an apparent decrease</u>

Blue-faced Booby
Red-footed Booby

<u>Species in which there was no apparent change</u>

Black-footed Albatross
Bonin Petrel
Wedge-tailed Shearwater
Christmas Shearwater
Brown Booby
Great Frigatebird
American Golden Plover
Ruddy Turnstone
Bristle-thighed Curlew
Wandering Tattler
Gray-backed Tern
Black Noddy
White Tern

Support for this idea is provided by the following: (1) although available habitat increased for Black Noddies and White Terns, both of which breed abundantly at Midway, the former apparently did not increase at Kure and the latter did not breed there at all; neither was extensively harassed at Midway; (2) species, such as the Blue-faced Booby and Brown Booby, which bred in the central plain, generally did not increase or change their distribution on the island (i.e., they still bred only in the central plain), suggesting that more than increased habitat is necessary for colonization of an island.

Since Brown Noddies bred on Sand Island, Kure Atoll, they may have moved to Green Island after the habitat alteration. This species is also the most likely one to colonize new areas as they breed on bare sand. Sooty Storm Petrels were probably overlooked by earlier observers, while Red-tailed Tropicbirds may have increased slightly. Ecotonal regions favored by the former species also increased.

Why the Blue-faced Booby population declined is unclear but may be related to the disturbance of the breeding colony during construction. It is possible the Red-footed Boobies did not decrease although their breeding habitat decreased in size. During POBSP studies Red-footed Boobies did not breed in all available habitat so there is no reason to assume that they decreased because their habitat decreased. Perhaps only their distribution on the island changed.

Annual Population Cycles

Figures APC-1 and 2 show the relative abundance and occurrence of avian species throughout the year at Kure Atoll. The width of the bar indicates the relative abundance of each species unto itself, not in comparison with the other species.

Six basic patterns are evident: (1) present all year, most abundant in spring and summer (e.g., Red-footed Booby, Great Frigatebird); (2) present all year, most abundant from fall through spring (e.g., shorebirds); (3) present from late fall through spring (e.g., albatrosses); (4) present from early spring to early fall (e.g., Sooty Tern, Gray-backed Tern); (5) present all year, no change in abundance (e.g., Blue-faced Booby); (6) present all year, most abundant in summer and fall (e.g., Brown Booby).

Breeding Cycles

Fourteen avian species definitely breed at Kure Atoll. Another, the Sooty Storm Petrel, probably breeds, but no eggs or young were found. Figure BC-1 shows the generalized breeding cycle of each of these species, based on the combined data collected during the six years of POBSP work.

All species had a well-defined annual cycle. In an extreme case, the Black-footed Albatross laid the first egg of each new breeding season on 14 November in all four years observers were present. Other species, such as the Blue-faced Booby, varied in the initiation of breeding as much as two months from year to year. However, in all species breeding began in the same one- to three-month period each year. Tables BC-1 and 2 show the period of egg laying, and the egg laying peak for each year for all species (except the Sooty Storm Petrel) breeding on Kure. Table BC-3 summarizes these periods for all years. As can be seen, the Black-footed Albatross, Laysan Albatross, Bonin Petrel, and Wedge-tailed Shearwater exhibited little or no yearly variation in the initiation of breeding, while the others varied, sometimes considerably, from year to year.

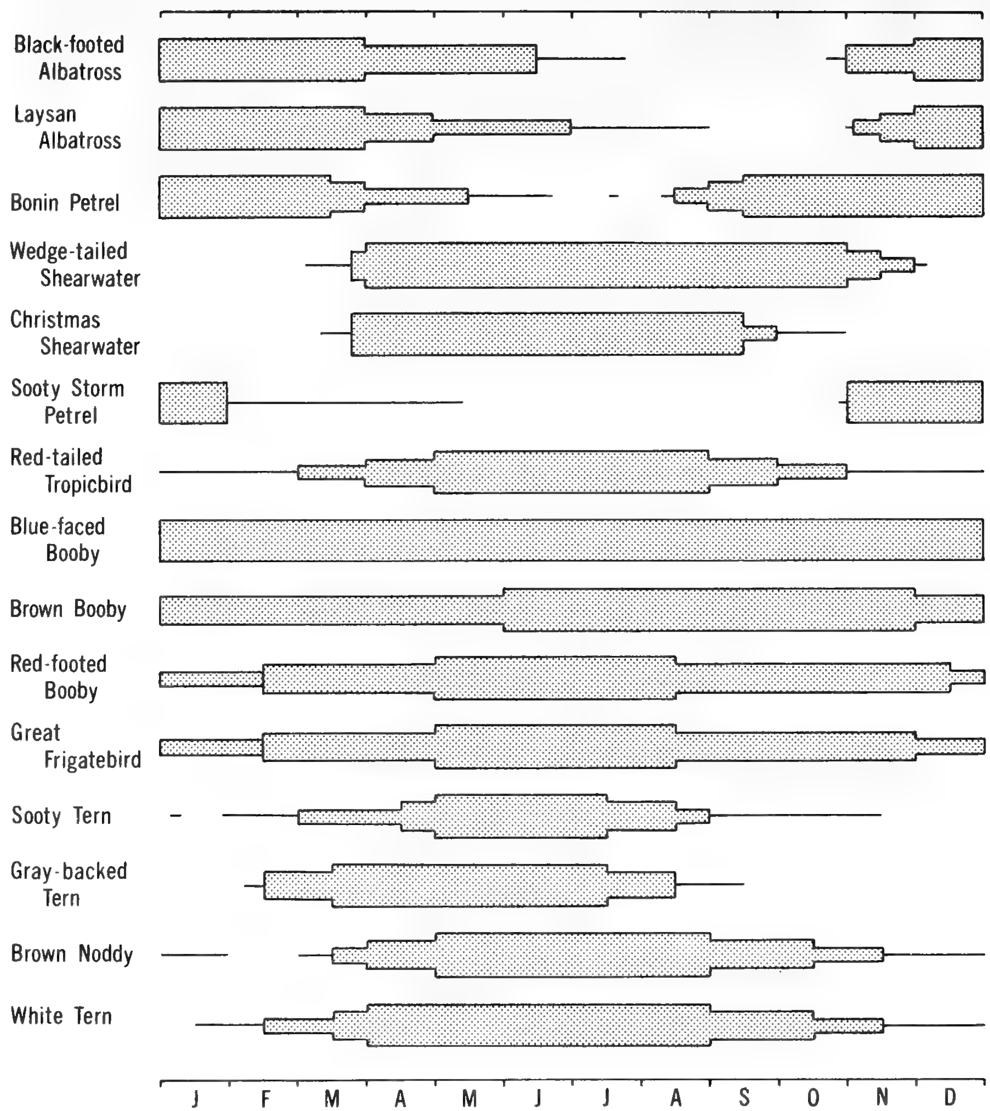

Figure APC-1. Generalized annual population cycles of breeding species at Kure Atoll.

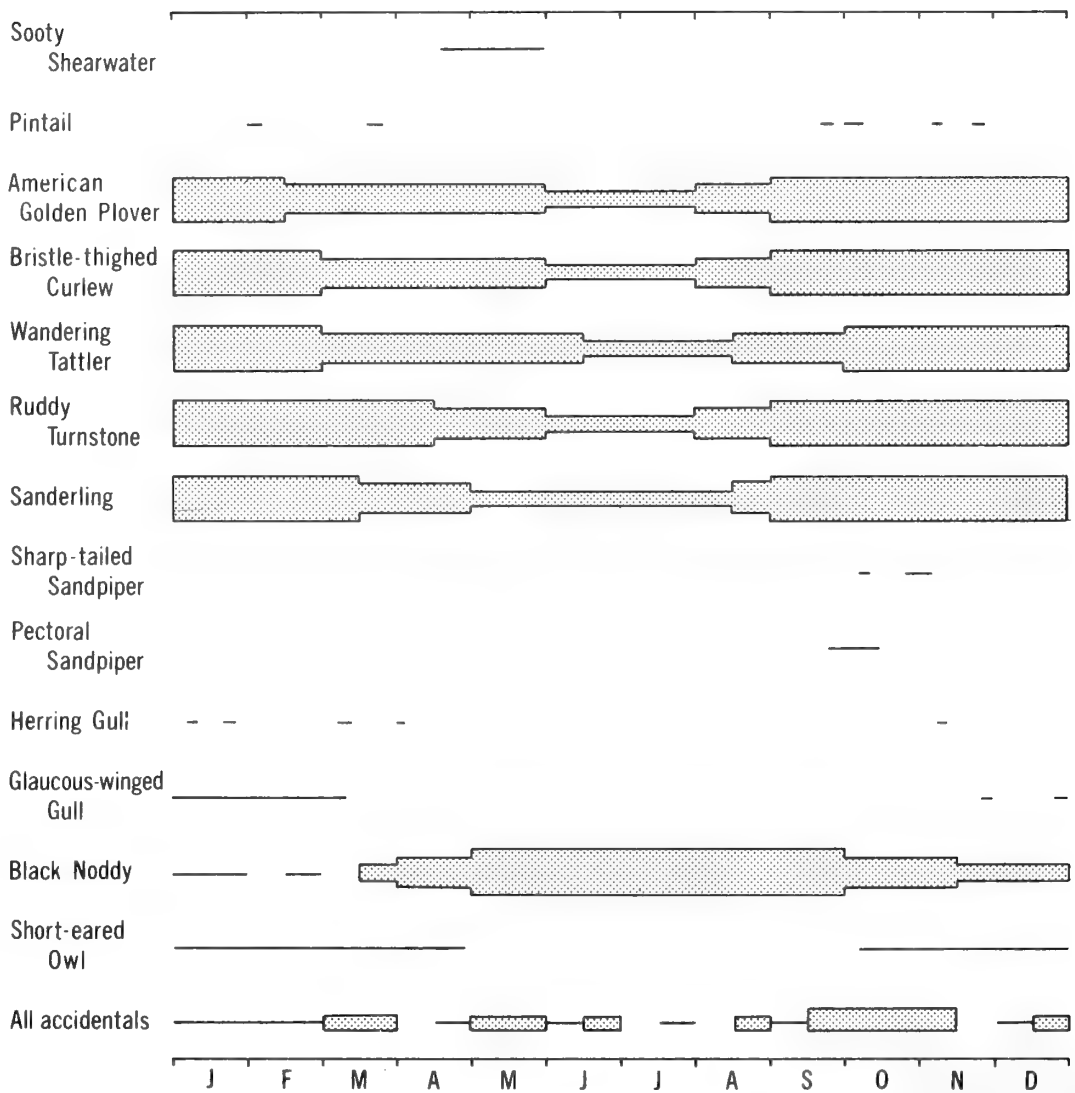

Figure APC-2. Generalized annual population cycles of non-breeding species at Kure Atoll.

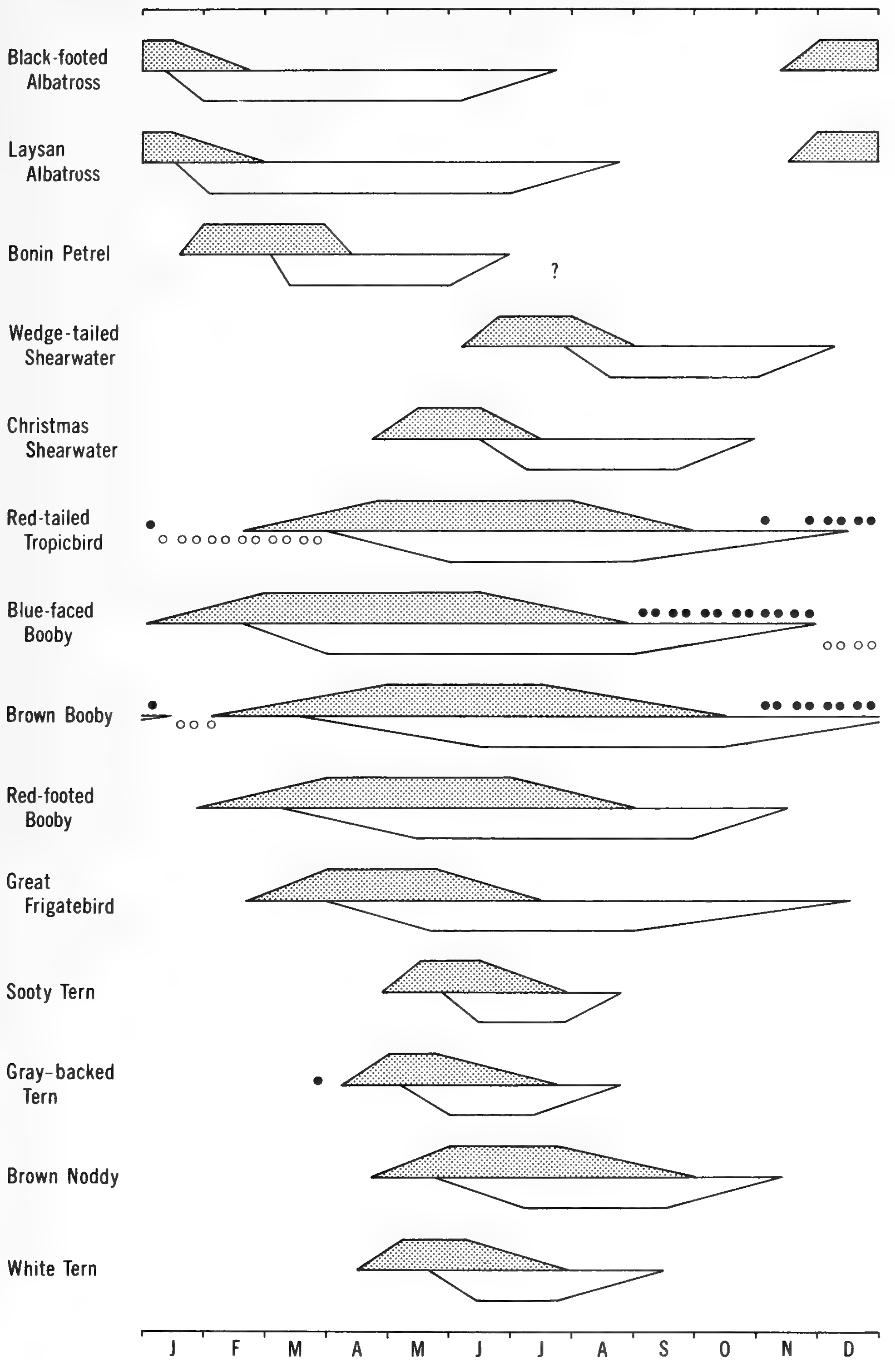

Figure BC-1. Generalized breeding cycles of avian species at Kure Atoll (dark areas are eggs, clear areas are young; dots indicate isolated sightings).

Table BC-1. Egg laying periods of avian species at Kure Atoll, 1964-69.

Species	1964	1965	1966	1967	1968	1969
Black-footed Albatross	14 November-mid-December	14 November-mid-December	14 November-mid-December	?	14 November-early December	--
Laysan Albatross	21 November-at least mid-December	20 November-at least mid-December	17 November-at least mid-December	?	19 November-mid-December	--
Bonin Petrel	23 January-mid-February	23 January-mid-February	?	?	?	*ca.* 17 January-19 February
Wedge-tailed Shearwater	Early June-early July	11 June-mid-July(?)	17 June-at least early July	8 June-at least late June	18 June-at least 2nd week July	12 June-?
Christmas Shearwater	At least late April	At least May	At least May	At least 2nd or 3rd week of May	At least 2nd or 3rd week of May and late June	At least May
Red-tailed Tropicbird	Early March-at least mid-July	Late February-at least early August	At least early March-at least mid-August	At least early March-at least early June	At least late March-at least mid-July	At least mid-March-at least early June
Blue-faced Booby	*ca.* 5 January-29 June	20 January-early August	At least early March-5 June	Early February-at least early July	*ca.* 29 January-17 June	*ca.* 21 January at least late May
Brown Booby	1 April-1 July	Late March-29 July	14 April-26 August	*ca.* 19 March-at least late June	*ca.* 8 February-28 August	Early April-at least early June

Table BC-1. (continued)

Species	1964	1965	1966	1967	1968	1969
Red-footed Booby	Late February-mid May	Late January, mid-March-at least end of June	Late March-early June	Early March-June	Early March-21 June	Late January-at least early May
Great Frigatebird	21 February-July (?)	Late February-early June	?-May	Early March-May	Early March-early May	Early March-at least early May
Sooty Tern	5 May-late May (?)	30 April-mid-June	6 May-mid-June	1 May-23 June	11 May-late June	_ca._ 25 April-late May
Gray-backed Tern	At least late April and early May	_ca._ 3 April-early June	Late April-3rd week May	_ca._ April 9-May 30	_ca._ 21 April-late June	At least late April and early May
Brown Noddy	13 May-late August	8 May-at least early August	12 May-late July	Late April-at least late June	18 May-early September	7 May-?
White Tern	At least May	At least early May	At least late May	_ca._ 18 April-7 May	_ca._ 26 April-25 June	At least late May

Table BC-2. Peak egg laying periods of avian species at Kure Atoll, 1964-69.

Species	1964	1965	1966	1967	1968	1969
Black-footed Albatross	Late November	Late November	Late November	?	Last 2 weeks November	--
Laysan Albatross	Late November-early December	_ca._ 28 November-12 December	Late November	?	25 November-10 December	--

Table BC-2. (continued)

Species	1964	1965	1966	1967	1968	1969
Bonin Petrel	Late January-early February	Early February (?)	?	?	?	*ca.* 25 January-10 February
Wedge-tailed Shearwater	Late June	Late June-early July	Late June	Late June	Late June	?
Christmas Shearwater	?	?	?	?	?	May
Red-tailed Tropicbird	First 2 weeks April-secondary one in June	May-mid-June	May-June	May-at least mid-June	Late May and June	Probably May
Blue-faced Booby	February-mid-March	None. Most eggs laid February and late March	None. Most eggs laid late March, late April, late May	Mid-March-mid-April	1-15 February, 15-31 March, late May-early June	Late January, February, and April
Brown Booby	Mid-April-late May	May	Last 2 weeks May	May	None. Most eggs laid in May and June	Late April-at least mid-May
Red-footed Booby	Late March-mid-April	3rd week May	Last week May	Late April	Late March, first 2 weeks June	Mid-March-mid-April
Great Frigatebird	Probably March or April	Last 2 weeks April	Early May	First 2 weeks April	Late March-3rd week April	Mid-March-mid-April
Sooty Tern	Late May?	6-17 May	15-25 May	1-21 May	3rd week May-1st week June	9-12 May

Table BC-2. (continued)

Species	1964	1965	1966	1967	1968	1969
Gray-backed Tern	?	Last 2 weeks June	Mid-May(?)	Last 2 weeks April	Last week April	?
Brown Noddy	June	Last week May-mid-June	First 2 weeks June	May	Last 2 weeks June-1st week July	?
White Tern	?	?	?	1st week May	26 April-11 May	?

Table BC-3. Range of egg laying and peak egg laying at Kure Atoll, 1964-69.

Species	Egg laying	Peak egg laying
Black-footed Albatross	November 14-mid-December	Late November
Laysan Albatross	November 17-mid-December	Late November-December 12
Bonin Petrel	January 17-mid-February	Late January-February 10
Wedge-tailed Shearwater	June 8-mid-July	Late June-early July
Christmas Shearwater	Late April-late June	May
Red-tailed Tropicbird	Late February-mid August	First 2 weeks April-June
Blue-faced Booby	January 5-early August	Late January-late May
Brown Booby	February 8-August 28	Mid-April-late May
Red-footed Booby	Late January-late June	Late March-mid-June
Great Frigatebird	February 21-early June	Mid-March-early May
Sooty Tern	April 25-late June	May 1-1st week June
Gray-backed Tern	April 3-late June	Mid-April-last 2 weeks June
Brown Noddy	Late April-early September	May-1st week July
White Tern	April 18-June 25	Late April-early May

Presumably the timing of these cycles reflects the periods for each species when food was most abundant for egg production and raising of young (see Lack, 1966, for full discussion). It is not surprising that, at Kure Atoll, with well-defined seasonal variation in air temperature, sea surface temperature, day length, et cetera, birds bred in well-defined cycles; their food supply probably varied regularly and predictably throughout the year. During POBSP studies only 4 Red-tailed Tropicbird, 2 Blue-faced Booby, and 8 Brown Booby nests were found outside the species' normal breeding periods. The majority of these nests failed, indicating that environmental conditions at these times were unfavorable.

It has been demonstrated on numerous occasions that lenghtening days stimulate breeding in temperate zone species (Rowan, 1929; Blanchard, 1941; Wolfson, 1952). At Kure the same stimulus is probably responsible for the initiation of breeding in spring and summer breeders. Shortening days may stimulate the albatross. Although the causes for these variations are unknown, it is probable that they are related to an actual scarcity or to the unavailability of food to the birds near the atoll. High winds, low temperatures, rain, and local storms are the most likely factors influencing food abundance and availability.

Factors Affecting Nesting Success

Details of nesting success are recorded in the appropriate Species Accounts. The following discussion summarizes those factors that affected success. Not all of them were equally important, and accurate quantitative data are lacking that showed the relative contribution of each, although rat predation and winter storms were obviously the most important.

Polynesian Rats

By far the most important factor affecting nesting success at Kure for most species was Polynesian Rat, *Rattus exulans*, predation. This mammalian predator has been present since at least 1870 when they were abundant (Read, 1912). Although unproven, it is probable that Polynesians accidentally introduced them long before Europeans discovered Kure. Thus, rats and birds have long been associated on Green Island, yet apparently no species has been extirpated by their predation.

The first record of rat predation was Robbins' (1966) observation that they ate Brown Noddy eggs that had been left uncovered for only a few minutes. Since 1963 an additional 9 species (Table NS-1) have been recorded as victims of rat predation. Laysan Albatross, Bonin Petrels, Red-tailed Tropicbirds, Sooty Terns, and Gray-backed Terns have suffered most heavily from this predation.

Adult and young birds that were attacked typically had open wounds, sometimes 1 to 2 inches in diameter, between the scapulae, slightly

anterior to the uropygial gland, or slightly posterior to the legs. Kepler (1967) describes the method of attack on Laysan Albatross in detail. Typical rat-damaged eggs were hollow, with a large opening at one end.

Predation was not equally intense in all years. In early 1964 only a few Laysan Albatross and Red-tailed Tropicbirds were preyed upon. By the time albatross began breeding again in the fall of 1964, and through the summer of 1965, predation was extremely heavy. Black-footed Albatross, Red-tailed Tropicbirds, Sooty Terns, and Brown Noddies were also victims of rat predation. The peak of predatory activity was reached in the spring and summer of 1966 when large numbers of birds were destroyed, the area of predation increased, and more species were recorded as being preyed upon.

Table NS-1. Avian species preyed upon by Polynesian rats on Green Island, Kure Atoll, 1963-69.

	Stage Preyed Upon		
Species	Eggs	Young	Adults
Black-footed Albatross		x	
Laysan Albatross		x	x
Bonin Petrel	x	x	
Wedge-tailed Shearwater	x	?	
Red-tailed Tropicbird	x	x	
Great Frigatebird			x
Sooty Tern	x	x	
Gray-backed Tern	x	x	
Brown Noddy	x	x	
White Tern		?	

One year later only young Sooty Terns were noted being eaten. Predation became serious again in 1968 when rats destroyed most eggs and young of Sooty Terns, and all young and eggs of Gray-backed Terns. However, no albatross were known to have been lost. From mid-December 1968 through February 1969 several Laysan Albatross were destroyed. By June 1969 rats were noted preying heavily on eggs and young of Red-tailed Tropicbirds.

Details of predation on each species are discussed below:

Black-footed Albatross: One nestling was eaten in early June 1965. In late April and early May 1966 at least seven nestlings in the northwest beach-*Scaevola* ecotone were destroyed. Nestlings on the open sand near the north point escaped predation.

Laysan Albatross: During the latter part of the 1963-64 breeding season at least 12 adults and a few nestling Laysans were eaten. In

the 1964-65 season over 50 adults and several nestlings were destroyed. The damage in these seasons was confined to the central plain, mainly the south antenna field.

Laysan Albatross suffered most heavily from predation in the 1965-66 breeding season. From 8 to 10 February 1966 Chandler S. Robbins found 57 adults that had been eaten by rats. Another two rat-destroyed adults were found in late April.

Robbins estimated that there were 310 nests, mainly with nestlings, northeast and east of the barracks, primarily in the north (90) and south (110) antenna fields. By mid-April only four remained: one in the north antenna field, one in the south antenna field, one along the northwest beach, and one adjacent to the central plain. Only the latter bird fledged; the others were eaten by rats during mid-May.

Robbins banded 400 nestlings in mid-March. At least 46 of these birds were eaten by rats. An additional 14 nestlings were destroyed in May and June. Predation was heaviest in the central plain, along the northwest beach, along the road to the pier, and behind the fuel tanks.

No predation was noted in 1967 or during the 1967-68 breeding season.

From mid-December 1968 through mid-January 1969 at least 32 adult Laysans were destroyed by rats. By February few adults were being molested by rats, but over 30 nestlings were killed and eaten, primarily along the runway, in the central roost, and along the southwest beach.

Bonin Petrel: Rats probably caused the complete breeding failure of this species from 1964 to 1968. Rats were commonly seen running in and out of burrows and the remains of eggs were found in these burrows.

To test this hypothesis, three study areas were established in 1969: one control area and two areas that were poisoned with Warfarin. No young Bonin Petrels were raised in the control area, but several fledged in the other two areas. Although other young fledged from areas that were not poisoned, it was probable that the poisoning had reduced the rat population in these areas as they were close to the study areas. One young Bonin Petrel, which was collected, had rat damage on the back.

Wedge-tailed Shearwater: Several egg shells broken in typical rat fashion were found. Rats were also suspected of eating chicks.

Red-tailed Tropicbird: In all years eggs and young of Red-tailed Tropicbirds were heavily preyed upon. Fleet (ms.) found that in 1964 53.6 percent of all eggs laid in a study area and 88.9 percent of nestlings hatched were lost to predation. Comparative figures for 1965 were 64.9 percent and 100 percent, respectively.

Great Frigatebird: On 16 May 1966 an adult male Great Frigatebird with a typical rat wound on its back was captured. Another adult male and 2 adult females with openings in the back were found on 10 June 1966. All of these birds were roosting. There was no evidence of predation on eggs or young.

Sooty Tern: In 1965 rats were seen carrying Sooty Tern eggs from the colony when the incubating birds were disturbed. They straddled the eggs and punctured the end before carrying them away. From 1966 to 1968 both eggs and young were destroyed by rats. In 1968 they destroyed all the eggs and young.

Gray-backed Tern: Two nestling Gray-backed Terns with openings in the back were found in May 1968. Eggs opened in typical rat fashion were also found. In 1968 the rats evidently destroyed all the eggs and young.

Brown Noddy: Both eggs and young were eaten. Nests on the open beaches generally escaped predation. In 1965 there was a 27.9 percent nestling loss in a two-week period. Only 8 of the 147 chicks lost were found, and all had wounds in the body cavity.

White Tern: A White Tern nestling with its whole back ripped open was found in June 1968. This bird may have been eaten by rats.

Discussion: Two distributional patterns of predation were noted. In those species, such as Brown Noddies and Red-tailed Tropicbirds, where only eggs or young were eaten, predation was widespread, occurring almost everywhere the species was present. The exception was individuals breeding on the open beaches who appeared to be immune to predation; individuals breeding in the densest vegetation appeared to be most susceptible.

In the case of Laysan Albatross, however, where adults were eaten, the area of predation was localized. In 1964-65 it was confined to the central plain, mainly the south antenna field. In spring 1966, predation was again extensive there, and had spread to areas north of the central plain, mainly along the northwest beach, where Black-footed Albatross were also eaten. By May it had progressed to the area by the barracks and behind the fuel tanks. Before the young fledged in July, a few along the runway were eaten. During the 1968-69 breeding season predation was noted along the runway, in the central roost, and along the southwest beach.

The localized nature of albatross predation suggests that only a small group of rats, which had learned to attack these large birds, was involved. Possibly they had overcome an initial fear of size. The fact that Fleet (ms.) found that tropicbird chicks more than 17 days old were not preyed upon supports this theory. Also, the progression of predation in 1966 suggests that a group was moving around the island attacking albatrosses.

As stated previously, predation reached a peak in 1966, when rats were extremely numerous. Starting in the fall of that year the Coast Guard began intensive poisoning around the island. By spring 1967 very few rats were noted, possibly as a result of the poisoning program or possibly as a naturally occurring population crash. Almost no predation was noted that year. In 1968 and 1969 rats were again numerous and predation was heavy. Thus, there was an apparent correlation with the number of rats present and the amount of predation.

Not all species were equally susceptible to predation. Species such as Red-footed Boobies or Sooty Terns, whose breeding adults were either aggressive towards intruders or flew away quickly when disturbed, were predation-free in the adult stage, while others such as Blue-faced Boobies, whose adults vigorously defended their young, were free from nestling predation. Apparently rats could not break through the shells of albatross and booby eggs, so these were not eaten.

The following model of predation is presented: Rats prey on eggs and young of many species every year, with the intensity of predation directly proportional to the size of the rat population. Another important factor is probably the amount of plant matter, which composes the bulk of the rats' diet (Wirtz, ms.). In years when plant food is scarce predation is heavier. During periods of peak rat abundance larger birds are preyed upon. The localized nature of this predation suggests that certain individuals learn to feed on larger birds and then move around the island. During the 1966-67 and 1967-68 albatross breeding cycles predation on albatrosses was reduced or eliminated, suggesting that most of the individuals that had learned to eat albatrosses had died. It seems likely that there must be this type of predation cycle (i.e., intensive one year, reduced the next) on these birds or otherwise they would have become extinct at Kure Atoll.

Storms

Winter storms, with accompanying winds and high water, accounted for much of the loss of albatross nests. In 1964 from 16 to 22 December the island was battered by winds up to 65 knots and received several inches of rain. Water came up over much of the western beach and ca. 400 yards of the ends of the island were washed away. During this storm 12 of 25 Black-footed Albatross study nests and at least 54 Laysan Albatross nests along the exposed lagoon beach were destroyed.

On 13 and 22 December 1968 storms with heavy winds hit the atoll. Several nests (exact number unknown) of both albatross species were destroyed by these storms. Some incubating adults were almost entirely buried by the drifting sands.

Although POBSP observers were not present during the complete albatross breeding cycle each season, late spring observations suggested that wind-blown high water was responsible for at least some nest loss

every year, especially along the eastern beach where water usually reached the Scaevola. In May 1968 the high-tide line along the lagoon beach was within 5 feet of the Scaevola and 3 to 4 feet of the vegetation along the edge showed evidence of extreme sand scouring.

High Tides

On 8-9 January 1969 water caused by high tides washed to the edge of the runway and into Scaevola along the northeast and southeast beaches. Several (exact number unknown) Black-footed Albatross nests were washed away.

In early September 1968 high tides washed away 5 Brown Noddy eggs at the north point. If these tides had occurred earlier in the year when most noddy nests contained eggs, almost all the nests would have been destroyed as the waves washed over the entire breeding area.

Rain

Heavy spring and summer rains were not known to have caused directly any nest loss, but an observation in May 1967 suggested that rain could indirectly be responsible in Red-footed Booby nest loss. After several days of heavy rains many Red-foot nests became waterlogged and were bending over. Possibly nestlings and eggs fall out if the nests become too heavy.

Undoubtedly long exposure of young birds to cold and rain could cause death, but this was probably a minor mortality factor.

Human Disturbance

Human disturbance affected nesting success indirectly, generally by causing the eggs or nestlings to be exposed to rain or cold. Some species, such as the Red-footed Booby, deserted their nests if handled or flushed repeatedly.

Great Frigatebird Predation

Although Great Frigatebirds are known to prey on other seabirds (Schreiber and Ashmole, 1970), none was seen to do so at Kure. However, when flushed from their nests, adult frigatebirds would occasionally return to the nest and peck a hole in the egg, or pick the nestling up, fly away, and drop it to the ground. This action probably occurs rarely in an undisturbed situation.

Great Frigatebirds also destroyed Red-footed Booby nests when humans flushed the boobies from them.

Seals

Seals occasionally destroyed nests when they hauled out. For example, on 26 May 1965 a seal crushed 18 Sooty Tern eggs in a study plot near the northeast beach.

Dogs

Dogs occasionally destroyed nestling Brown Noddies and probably nestling Christmas Shearwaters.

Starvation

No mass starvation, such as occurred on Ascension Island (Ashmole, 1963), was noted. However, every year a few emaciated Laysan Albatross nestlings were found. Some young Brown Boobies also apparently starved to death.

Miscellaneous Factors

Nesting success was also affected by infertile eggs, nest desertion, and adults attacking the young in such species as the Sooty Tern.

Movement

Through the recapture of previously banded birds it has become well established that seabirds of several species travel between various islands in the central Pacific Ocean. At Kure Atoll individuals of 13 species banded on other central Pacific islands or atolls were captured (Table M-1). In addition, an American Golden Plover and five Ruddy Turnstones banded in the Pribilof Islands, Alaska, were collected at Kure. Four hundred and sixteen individuals of fifteen species from Kure were recorded in the central Pacific (Table M-2). Figure M-1 shows the location of these islands.

Details of inter-island movement are recorded in the individual Species Accounts. Rigorous mathematical analysis of movement is difficult due to the following: (1) only a few individuals of some species were captured at Kure and/or banded on other islands, (2) some species were not banded on other islands, and (3) the banding and recapturing effort was inconsistent with respect to year and seasons--important parameters to consider in any analysis. Therefore, no detailed analysis of inter-island movement is attempted in this paper. Discussion of the movement of each species in the Hawaiian area will be published elsewhere.

Although the POBSP banded thousands of seabirds in the Line and Phoenix Islands, there was only one definite movement recorded between these areas and Kure Atoll. It appears that in the central Pacific movement to and from Kure Atoll was restricted to the Northwestern Hawaiian Islands, Wake Atoll, and Johnston Atoll.

Besides the inter-island movement in the central Pacific, forty-one individuals of seven species were recovered at sea or on islands outside the central Pacific. Figure M-2 shows the general location of these movements, which helps reveal the post-breeding dispersal patterns of several species. How much actual movement there was between Kure and

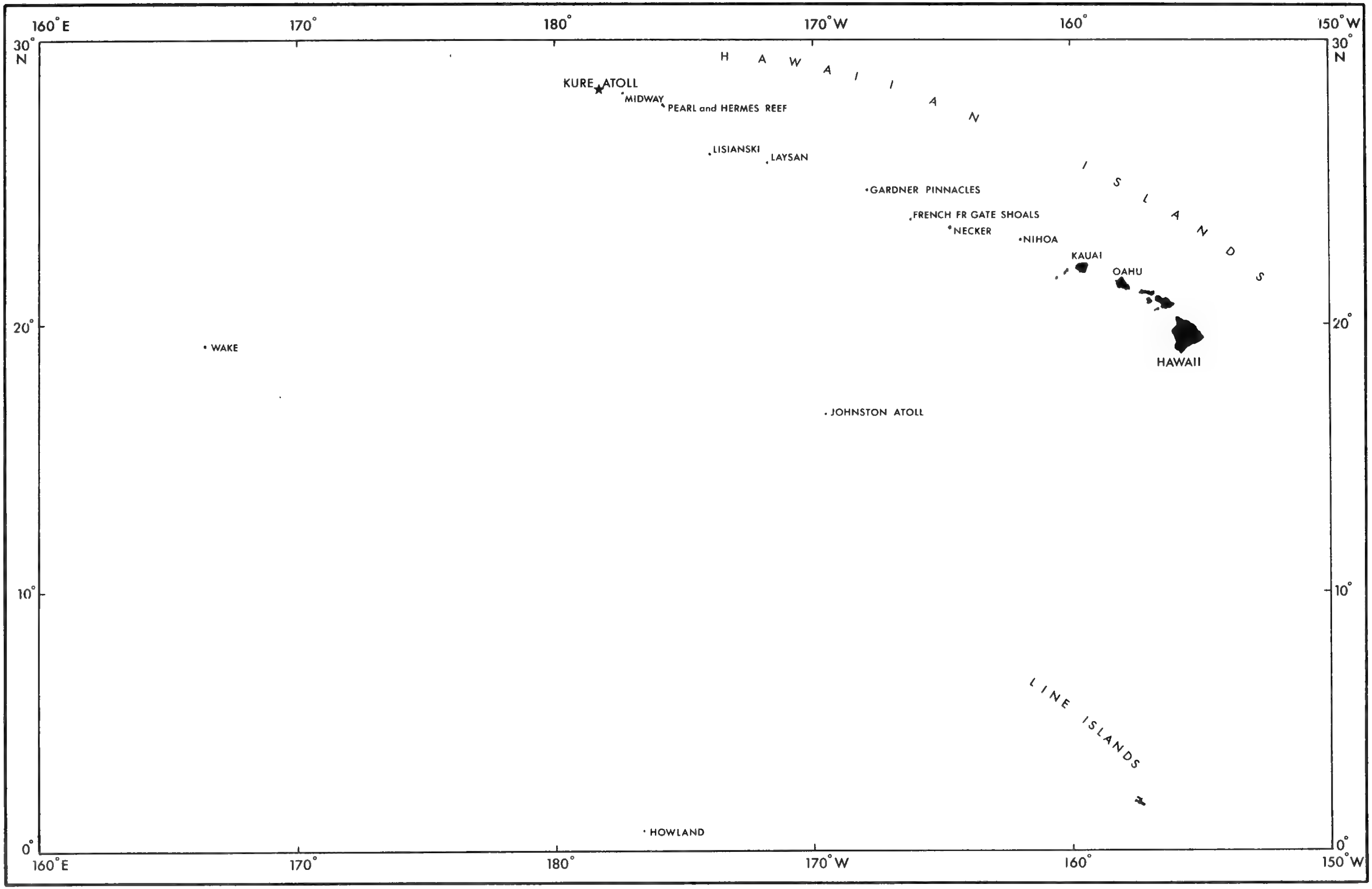

Figure M-1. Location of islands or atolls in central Pacific where Kure-banded birds have been recaptured or vice-versa.

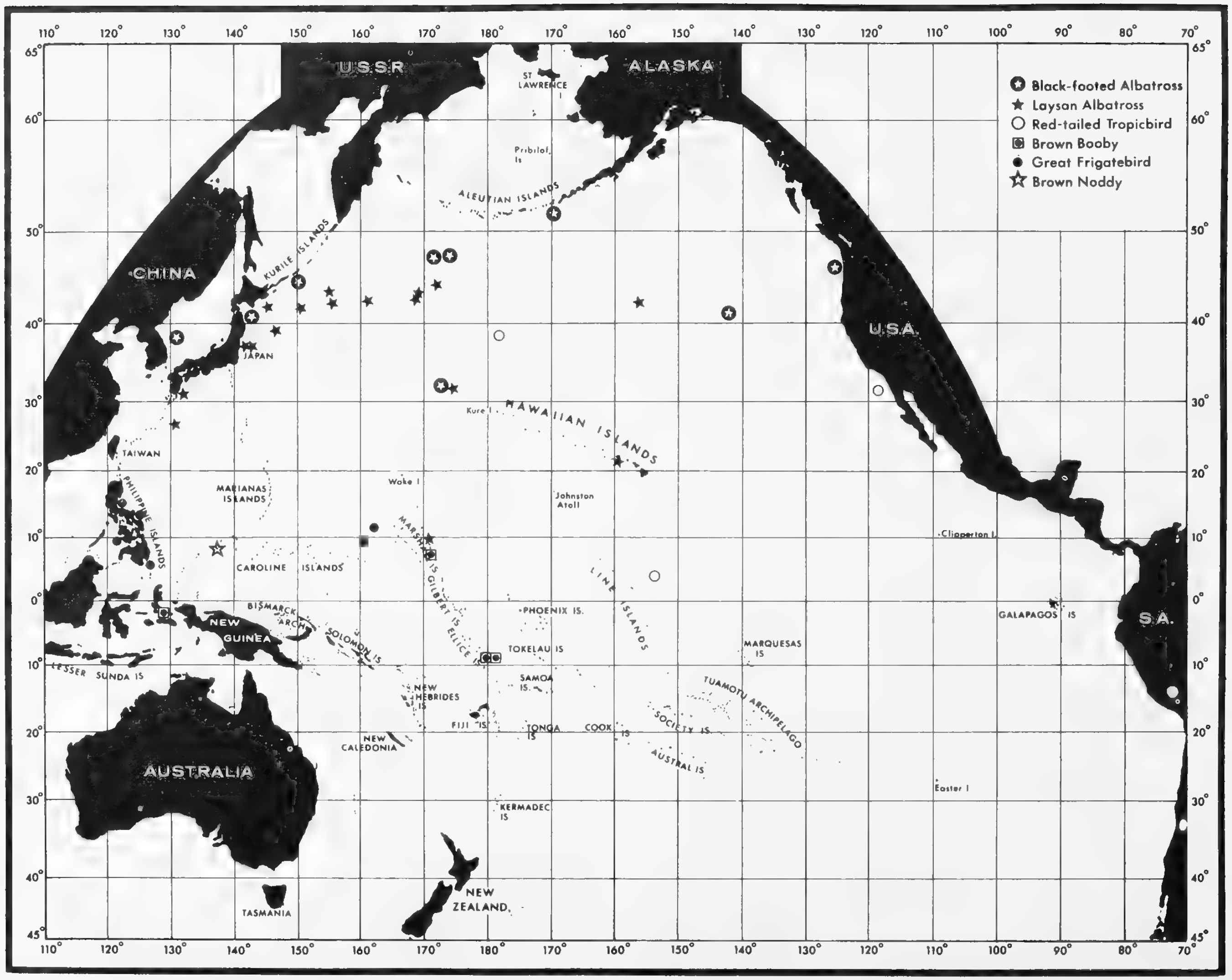

Figure M-2. Locations of birds banded at Kure Atoll and recovered at sea or outside the central Pacific.

Table M-1. Birds banded on other islands in the central Pacific and recaptured at Kure Atoll, 1959-69.

	Midway Atoll	Pearl and Hermes Reef	Lisianski	Laysan	French Frigate Shoals	Nihoa	Kauai	Oahu	Johnston Atoll	Wake Atoll	Howland	Totals
Distance (nautical miles)	49	135	266	379	695	926	1,072	1,175	838	978	1,634	
Species												
Black-footed Albatross	133	23	0	0	2	0	-	-	-	-	-	158
Laysan Albatross	536	22	5	2	0	0	-	-	-	-	-	565
Bonin Petrel	5	3	3	0	1	-	-	-	-	-	-	12
Wedge-tailed Shearwater	0	0	0	0	2	0	2	0	0	0	-	4
Red-tailed Tropicbird	1	0	0	0	0	0	-	-	1	0	0	2
Blue-faced Booby	1	3	5	0	4	0	-	0	0	0	0	13
Brown Booby	1	4	0	0	0	0	-	0	0	0	1	6
Red-footed Booby	26	5	6	6	13	0	1	2	15	16	0	90
Great Frigatebird	3	42	3	5	10	1	-	-	4	0	0	68
American Golden Plover	0	0	1	0	0	-	-	0	0	-	0	1
Sooty Tern	554	2	0	4	0	-	-	0	14	1	0	575
Brown Noddy	2	0	0	0	0	0	-	0	0	0	0	2
Black Noddy	16	3	1	0	3	-	-	-	1	-	-	24
Totals	1,278	107	24	17	35	1	3	2	35	17	1	1,520

Table M-2. Birds banded at Kure Atoll and recaptured at other locations in the central Pacific.

Distance (nautical miles)	Midway Atoll 49	Pearl and Hermes Reef 135	Lisianski 266	Laysan 379	French Frigate Shoals 695	Johnston Atoll 838	Wake Atoll 978	Totals
Species								
Black-footed Albatross	24	6	1	0	0	-	-	31
Laysan Albatross	100	2	0	1	1	-	-	104
Bonin Petrel	0	3	0	0	0	-	-	3
Wedge-tailed Shearwater	0	1	0	0	0	0	-	1
Red-tailed Tropicbird	0	0	0	0	1	0	0	1
Blue-faced Booby	5	1	3	1	1	2	0	13
Brown Booby	0	1	0	0	0	0	1	2
Red-footed Booby	34	4	8	1	13	26	2	88
Great Frigatebird	4	1	3	1	8	0	0	17
American Golden Plover	1	0	0	0	0	0	0	1
Bristle-thighed Curlew	1	0	0	0	-	-	-	1
Ruddy Turnstone	1	0	0	0	0	0	0	1
Sooty Tern	133	5	0	2	0	6	1	147
Brown Noddy	2	0	1	0	0	0	0	3
Black Noddy	1	0	0	0	1	0	-	2
Totals	306	24	16	6	25	34	4	415

the Marshall Islands is unknown due to the small number of birds banded there and the limited recapturing effort in that area. It may well be that the Marshalls are part of the normal range for Kure birds such as Red-footed Boobies and Great Frigatebirds. Recovery records show a generally southerly or westerly movement from Kure outside the central Pacific, but this may simply be the result of the greater probability of recapturing birds in the western Pacific because of the greater number of islands in that area compared to the eastern Pacific.

In summary, seabirds from Kure Atoll moved commonly to other islands in the Northwestern Hawaiian Chain, to Wake Atoll, Johnston Atoll, to a lesser extent to the Marshall Islands, and less frequently throughout the Pacific Basin--to California, to Japan, to Indonesia, and to the North Pacific.

Species Accounts

In the following accounts the observations refer only to Green Island. Sand Island observations are summarized later. The reader is referred to Figure K-1 for the locations of the various areas discussed in the text.

BLACK-FOOTED ALBATROSS — *Diomedea nigripes*

Status

Abundant winter-spring breeder; 200 to 350 pairs annually. Present from late October to third week of July. Breeding begins in mid-November and continues until the last young depart in July.

Populations

Black-footed Albatross were first recorded from Kure Atoll by George H. Read (1912) of the U.S.S. *Saginaw*. He reported that "the main source of food will be the seal and brown albatrosses. Both seem plentiful..." and that the albatrosses were nesting at the extreme westward point. Lt. Commander Montgomery Sicard, Captain of the *Saginaw*, reported (in the Annual Report of the Secretary of the Navy on Operations of the Department for the year 1871) in a letter to Rear Admiral John A. Winslow: "As regards food, I commenced by sending out parties to kill seal and birds, but after about a month I found that, owing to the rapid diminuation of the seal, I was obliged to cut the allowance down, and killed one seal and twenty birds per day for the whole crew." Therefore, *ca*. 600 albatross were killed in December 1870 and an unknown number, probably in the hundreds, in November 1870, indicating a Black-footed Albatross population of the same order of magnitude as was found in the early part of this century (Table BFA-1) and during POBSP studies (Table BFA-2), but considerably higher than Kenyon and Rice's 1957 and 1958 counts.

Table BFA-1. Previous records of Black-footed Albatross on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1870-71	October 29-January 4	?	"Brown Albatrosses" eaten by crew of U.S.S. Saginaw. Found nesting at extreme point to the westward (Read, 1912: 32, 68).
1915	March 28	1,500	Nesting in small colonies along the northern shore, western end. Few along the southern shore (Munter, 1915: 137).
1918	September 15	?	Offshore (R.G. 45, Nat. Archives, Report of Commanding Officer U.S.S. Hermes to Commandant 14th Naval District).
1923	April 17-22	ca. 600	300 nesting pairs. Well-grown downy young in little colonies on open sandspits or scattered along beaches (Wetmore, ms.).
1956	December 9	?	Aerial count of 2,200 of both albatross species (Aldrich et al., ms.).
	December 21	?	Group of 64 counted from the air (Kenyon and Rice, 1958: 189).
1957	June 5	ca. 163	Estimated 50 young: count of 14 nestlings along south beach and 28 along north beach. 10 unemployed birds seen (Kenyon and Rice, 1958: 188-9).
1958	May 9	?	Estimated 50 young (Rice and Kenyon, 1962: 367).
1959	October 3-8	0	(Robbins, 1966: 53).
1960	March 28	280+	95 nesting pairs; 280 adults on island at one time (Robbins, 1966: 53).
1961	January 19-21	320+	160 nesting pairs; 200 adults on island at one time (Robbins, 1966: 53).
	September 12-14	0	(Udvardy, 1961).
1962	February 2-4	130+	65 nesting pairs; 100 adults on island at one time (Robbins, 1966: 53).
	August 6-8	0	(Robbins, 1966: 53).
1963	February 3-7	400+	200 nesting pairs; 235 adults on island at any one time (Robbins, 1966: 53).

Table BFA-2. POBSP semi-monthly estimates of Black-footed Albatross on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	650	700	-	500	-	700
16-31	-	650	700	*	-	-	700
February							
1-15	-	*	700	325	550	-	750
16-28	*	650	600	-	-	-	1,000
March							
1-15	-	550	600	-	-	-	820
16-31	-	550	600	*	*	400	780
April							
1-15	-	275	400	-	-	-	675
16-30	-	275	300	300	-	-	400
May							
1-15	100	275	300	225	433	-	400
16-31	-	275	250	200	402	396	380
June							
1-15	-	200	235	182	404	392	310
16-30	-	48	150	28	*	48	*
July							
1-15	-	4	6	4	*	2	-
16-31	-	*	2	0	-	0	-
August							
1-15	-	0	0	0	-	0	-
16-31	-	0	-	0	-	0	-
September							
1-15	-	0	-	0	-	0	-
16-30	0	0	-	0	-	0	-
October							
1-15	0	0	-	-	-	0	-
16-31	*	11	-	-	-	*	-
November							
1-15	325	275	-	-	-	*	-
16-30	475	500	550	-	-	*	-
December							
1-15	570	700	550	-	-	*	-
16-31	650	700	-	500	-	*	-

*Birds present, number unknown

Whether or not the population increased from 1957 to 1963 is difficult to determine without early season estimates. POBSP data clearly demonstrate the fallacy of comparing estimates made late in the breeding season. For example, in May 1966 104 nestlings were counted; one year later 200 were present. It could easily be concluded that the breeding population had doubled in size, but in reality it was approximately the same both years as determined by December nest estimates. The differences in number of nestlings resulted from varying rates of nest loss each year. How much nest loss there was in 1957 is unknown but it probably was considerable since a tidal wave hit the atoll on 9 March 1957 (Rice, 1959: 19), two months prior to the Kure census.

Breeding Black-footed Albatross were easily enumerated because of the relatively small numbers involved and the conspicuousness of their nests. In three of the six breeding seasons that POBSP personnel worked on the island, accurate nest counts were made early in the season; accurate nestling counts were made late in all seasons. These data indicated a yearly breeding population of 235 to 335 pairs.

In contrast to estimates of breeders, estimates of non-breeders were inadequate. Generally they were based on a few counts and on the individual observer's judgment. From 26 December 1964 to 27 February 1965, and from February to June 1969, however, counts of non-breeders were made each week (Tables BFA-3-4). In 1969 most breeding Black-foots were streamered to facilitate recognition. These data showed that non-breeding Black-footed Albatross composed 0 to 55 percent of the total population using the island during a week.

The only other population data of importance were the number of Black-footed Albatross captured during an entire breeding season (Table BFA-5). In 1963-64 almost four times as many birds were caught as the highest nest count. Assuming that all breeding birds were handled, the non-breeding population at least equaled the breeding population in size. At the same time it was estimated that only 335 individuals, including 235 breeders, were present at any one time. Obviously there was a large daily turnover. Evidently many of these birds were from Midway Atoll (see Banding and Movements), 49 miles to the southeast, and some were subadults returning to the atoll for the first time.

The banding history of the 309 non-breeders captured in 1968-69 indicates the general structure of this population. Thirty-nine of these birds (12.6 percent) had bred in previous years at Kure, 106 (34.3 percent) were raised at Kure but had not bred yet, 12 (3.9 percent) had been banded on other islands, 21 (6.8 percent) had been banded at Kure but were not found breeding there, and 131 (42.4 percent) were unbanded. These latter birds were most likely raised on other islands. Therefore, the majority (53.1 percent) of non-breeding Black-footed Albatross was not of Kure origin.

Table BFA-3. Counts of non-breeding Black-footed Albatross, Green Island, Kure Atoll, 1964-65.

Date of Count	Number of Non-breeders	Percent of Total Population*
December 26	155	29.0
31	236	38.2
January 1	165	30.2
16	182	36.4
23	123	27.9
30	233	42.1
February 6	331	55.3
13	110	29.3
20	124	31.9
27	153	26.7

* Total population includes the number of non-breeders and twice the number of active nests.

Table BFA-4. Counts of non-breeding Black-footed Albatross, Green Island, Kure Atoll, 1969.

Date of Count	Number of Non-breeders	Percent of Total Population*
February 24	170	34.6
March 3-5	150	33.4
10-11	125	29.4
17-18	80	21.0
24-25	80	21.0
31	250	45.5
April 11-14	110	26.8
20-21	80	21.0
29-30	60	16.7
May 5-6	50	14.3
12	10	3.2
20	3	1.0
26	0	0.0
June 2-3	10	3.3
9	1	0.3
16	0	0.0

*Total population includes the number of non-breeders and twice the number of active nests.

Table BFA-5. Number of Black-footed Albatross handled during several breeding seasons on Green Island, Kure Atoll.

Breeding Season	Breeding Birds	Non-breeding Birds[1]	Total
1963-64	216	776	992
1964-65	305	409	714
1965-66	314	208	522
1966-67	216	49	265
1968-69	538	382[2]	920

[1] Many of these individuals were probably breeding but were not found on nests.

[2] Almost all definitely not breeding.

Annual Cycle

Black-footed Albatross arrived on 24 October 1963, 25 October 1964, and 29 October 1968. The September 1918 record is unique. The population increased slowly at first and it was not until mid-November that large numbers of albatross were present. By mid-December the population peak, which continued through February (1965) and March (1964, 1969), was reached. Non-breeding birds were common from at least late December through March. In April they began to decrease rapidly until they were almost all gone by mid-May. After February, breeding Black-foots returned to the island only briefly to feed their young, so most albatross seen on the island at this time were non-breeders.

Limited data show that 5-year old Black-footed Albatross were present from at least December through April, 4-year old birds from at least February to late May, 3-year old birds from at least February to mid-May, and 2-year old birds from early March to early May. Some 5-year Black-footed Albatross bred (three records in 1969).

Black-footed Albatross bred on a well-defined annual cycle that showed almost no yearly variation. Figure BFA-1 shows the 1964-65 cycle when the most accurate data were collected.

The first egg was laid on 14 November in 1963, 1964, 1965, and 1968. Egg laying continued through mid-December, with a peak the last two weeks of November. From 64 to 70 days ($\bar{x}$=67, n=11) after laying, the eggs hatched; the first egg hatched on 19 January in 1964, 14 January in 1965, 17 January in 1966, and 18 January in 1969. Hatching continued through the third week of February, with a peak the last two weeks of January.

One of the pair remained with the nestling 15 to 29 days ($\bar{x}$=22.1, n=35) after hatching. Afterwards both adults returned periodically to feed their young. The fledging period for young Black-footed Albatross was from 137 to 170 days ($\bar{x}$=151.2, n=13); the first young fledged in mid-June and the last one by: 18 July in 1964, 20 July in 1965, mid-July in 1966, and 18 July in 1968. Most young left the atoll in late June or early July. These young did not return to Kure for at least one and one-half years after fledging.

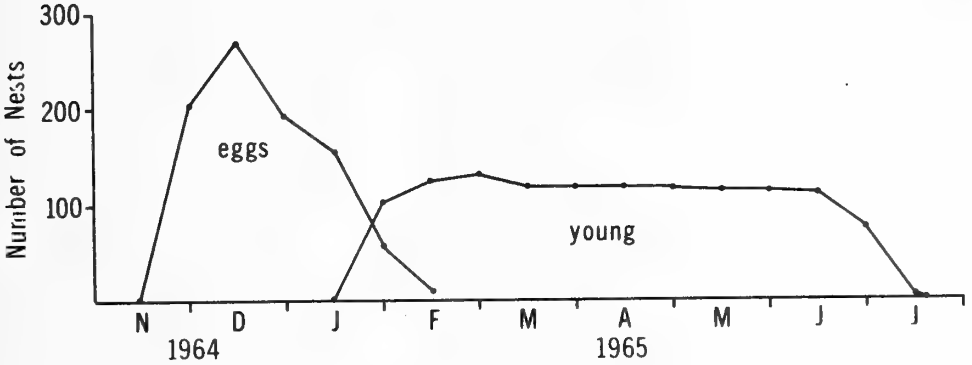

Figure BFA-1. Breeding cycle of Black-footed Albatross on Green Island, Kure Atoll, 1964-65.

Nesting Success

Table BFA-6 summarizes Black-footed Albatross productivity for 1963 to 1969. Major factors in nest loss were winter storms, especially in 1964-65 and 1968-69, which washed away or buried nests with blowing sands, and rat predation in 1966.

Hatching success was calculated in 1963-64 from 50 nests as 66 percent, in 1964-65 from 30 nests as 36.7 percent, and in 1968-69 from 331 nests as 57.7 percent. Thirty-three percent of the loss in 1964-65 was due to a storm which washed away 10 of the nests. Eighteen (36 percent of eggs laid and 54.5 percent of eggs that hatched) of the young fledged in 1963-64, and 145 (43.8 percent of eggs laid and 75.9 percent of eggs that hatched) fledged in 1968-69. In the incomplete study of 1964-65, nine young (36 percent of eggs laid and 81.8 percent of eggs that hatched) remained on 30 April.

Crude rates of survival to maturity of nestling Black-footed Albatross were obtained (Table BFA-7). Although inexact the figures for the 4- and 5-year old birds are probably accurate in a general way as they will be breeding in a year or two and the ones that are still alive should be on the island. The lower rates for the 1966 and 1967 cohorts reflect the greater tendency of 2- and 3-year old albatross to remain away from the island.

Table BFA-6. Productivity of Black-footed Albatross on Green Island, Kure Atoll, 1963-69.

Breeding Season	Maximum Egg Count or Estimate	Maximum Nestling Count or Estimate	Number of Nestlings Banded	Approximate Number of Nestlings Fledged	Percent Fledged from Maximum Number of Nests
1963-64	235[1]	200	60	100	42.6
1964-65	271[1]	132[1]	117[3]	117	43.2
1965-66	200	122	104[3]	91	45.5
1966-67	200+	218[2]	200[3]	195	--
1967-68	--	204	204[3]	191	--
1968-69	331[1]	191[1]	145	145	43.8

[1] POBSP count. [2] C.S. Robbins count. [3] Represents all nestlings present at time of banding.

Table BFA-7. Recapture rates of Black-footed Albatross banded as nestlings at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1959-60	8	100.0	50.0 (0.0)	50.0 (0.0)	50.0 (0.0)	50.0 (0.0)	50.0 (37.5)	25.0 (0.0)	25.0 (12.5)	12.5 (0.0)	12.5 (12.5)
1960-61	40	--	100.0	30.0 (0.0)	30.0 (0.0)	30.0 (0.0)	30.0 (22.5)	17.5 (2.5)	17.5 (0.0)	17.5 (0.0)	17.5 (17.5)
1963-64	60	--	--	--	--	100.0	20.0 (0.0)	20.0 (0.0)	20.0 (0.0)	20.0 (0.0)	20.0 (20.0)
1964-65	117	--	--	--	--	--	100.0	34.2 (0.0)	34.2 (0.9)	34.2 (2.6)	34.2 (34.2)
1965-66	104	--	--	--	--	--	--	100.0	27.9 (0.0)	27.9 (0.0)	27.9 (27.9)

Table BFA-7. (continued)

Breeding Season Banded	n.	Breeding Season Recaptured 1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1966-67	200	--	--	--	--	--	--	--	100.0	13.5 (0.0)	13.5 (13.5)
1967-68	204	--	--	--	--	--	--	--	--	100.0	0.0 (0.0)
1968-69	145	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Ecology

Black-footed Albatross bred mainly around the island's perimeter on the open beaches and the beach-_Scaevola_ ecotone. A few pairs also bred at the east end of the runway in the sand-_Eragrostis_ association, along the east side of the runway, and in the open area at the southwest end of the runway. They laid their single egg in a simple depression in the sand to which occasional bits of vegetation had been added.

The main concentration of nests was along the southwest beach and near the north point (Fig. BFA-2). In 1967, 61.5 percent of the nests were along the lagoon beach. This tendency for nests to be more common along the western beach than the eastern one was noted in all years by the POBSP.

Non-breeding Black-footed Albatross roosted in the same areas as breeding birds. Before fledging the young albatross congregated on the beaches, generally near the water.

Banding and Movements

From 1960 through 1969 1,614 adult Black-footed Albatross were banded at Kure Atoll. Recapture rates of these birds from one breeding season to the next were high (Tables BFA-8-9) and probably approached the survival rate. As would be expected, however, Black-foots banded as breeders were recaptured more frequently than birds banded as non-breeders.

Thirty-one adult Black-footed Albatross were recaptured on other islands: 24 at Midway, 6 at Pearl and Hermes Reef, and 1 on Lisianski. One of the Midway birds bred there. Ad adult banded at Kure on 16 November 1963 was recaptured on Southeast Island, Pearl and Hermes Reef, on 13 March 1964 and then was found breeding at Kure on 5 December 1968.

Eight hundred and seventy-nine nestling Black-footed Albatross were banded. The recapture of these birds has been summarized previously.

Recovery of Kure-banded Black-footed Albatross at sea showed a general northeasterly post-breeding dispersal from Kure (Table BFA-10).

One hundred and fifty-eight Black-footed Albatross banded on other islands were recaptured at Kure. The majority (133) was from Midway Atoll. Most of these birds had been banded by Dale W. Rice, Chandler S. Robbins, and Eugene Kridler of the United States Fish and Wildlife Service, and Harvey I. Fisher of the University of Southern Illinois. One hundred and twenty-four were nestlings at the time of banding and 22 bred at Kure.

Twenty-three of these Black-foots were banded at Pearl and Hermes Reef (10 as nestlings). Nine bred at Kure, but not at Pearl and Hermes. In addition, two nestlings banded at French Frigate Shoals, one in June 1963 and the other in June 1966, were captured. The 1963 banded Black-foot bred at Kure.

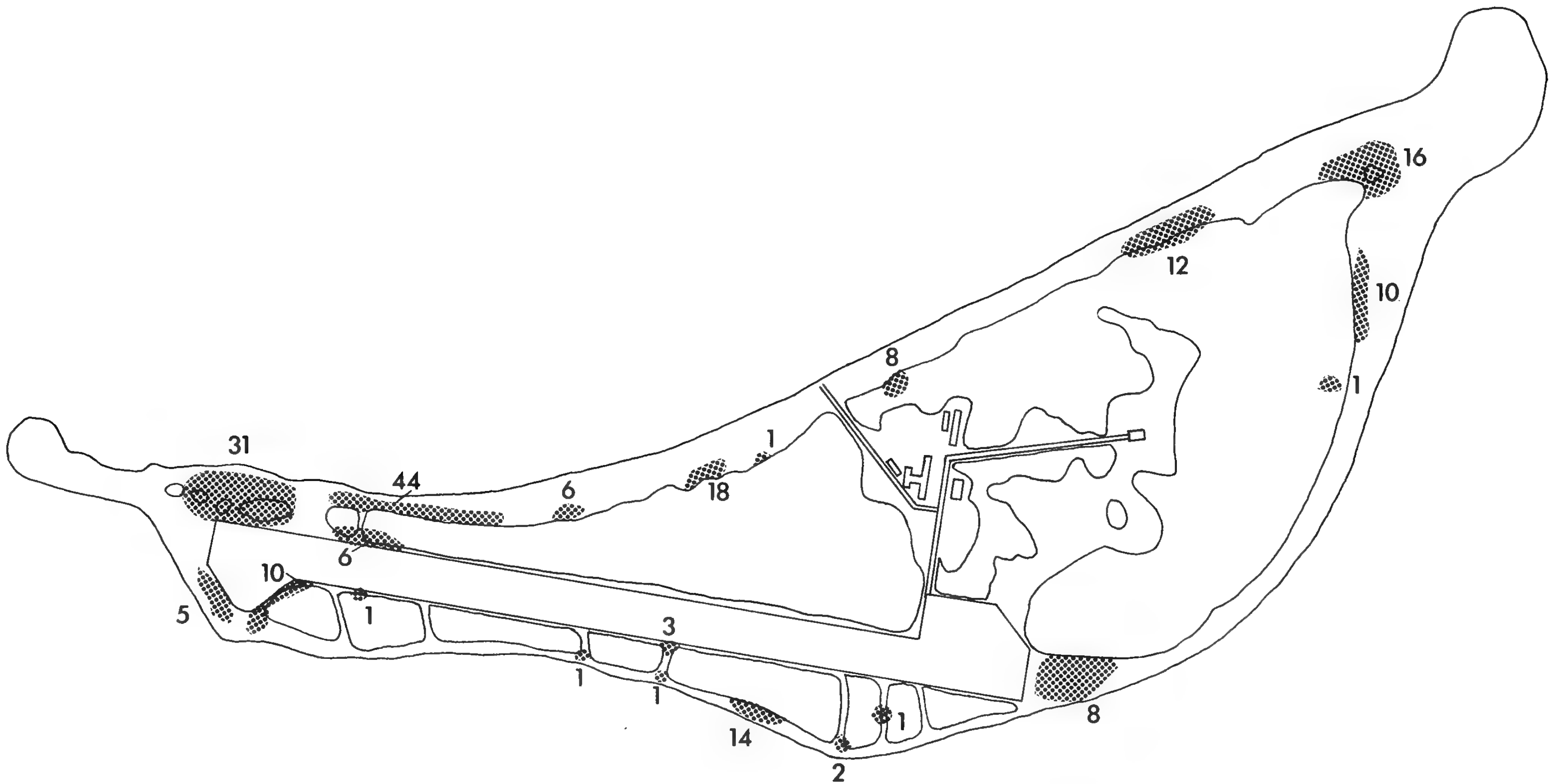

Figure BFA-2. Distribution and abundance of breeding Black-footed Albatross on Green Island, Kure Atoll, May 1967

Table BFA-8. Recapture rates of adult Black-footed Albatross banded as breeders at Kure Atoll and recaptured there (expressed as percentages), 1960-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1960-61	193	100.0	79.8 (23.8)	77.7 (40.9)	75.1 (61.7)	65.8 (54.4)	52.3 (26.9)	40.9 (18.1)	36.8 (5.2)	36.8 (36.8)
1961-62	48	--	100.0	93.8 (27.1)	93.8 (87.5)	83.3 (72.9)	72.9 (18.8)	68.8 (31.3)	66.7 (20.8)	66.7 (66.7)
1962-63	138	--	--	100.0	87.7 (73.2)	79.0 (66.7)	65.9 (28.3)	59.4 (26.8)	49.3 (14.5)	49.3 (49.3)
1963-64	117	--	--	--	100.0	82.9 (53.9)	72.7 (54.7)	58.1 (24.8)	49.6 (0.0)	49.6 (49.6)
1965-66	3	--	--	--	--	--	100.0	66.7 (66.7)	66.7 (0.0)	66.7 (66.7)
1968-69	86	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the number of birds captured.

Table BFA-9. Recapture rates of adult Black-footed Albatross banded as non-breeders at Kure Atoll and recaptured there (expressed as percentages), 1960-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1963-64	597	100.0	52.4 (34.5)	45.4 (32.3)	34.0 (15.6)	29.3 (3.4)	29.2 (29.2)
1964-65	168	--	100.0	39.3 (13.1)	35.1 (11.3)	29.2 (11.2)	28.6 (28.6)
1965-66	113	--	--	100.0	25.7 (8.0)	23.0 (0.0)	23.0 (23.0)

Table BFA-9. (continued)

Breeding Season Banded	n.	Breeding Season Recaptured 1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1966-67	20	--	--	--	100.0	25.0 (0.0)	25.0 (25.0)
1968-69	131	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the number of birds captured.

Table BFA-10. Black-footed Albatross banded at Kure Atoll and recovered outside the central Pacific.

Date Banded	Age at time of Banding	Where Found	When Found
28 March 1960	Nestling	40°40'N 142°40'W	4 July 1962
17 January 1963	Breeding adult*	41°50'N 141°10'E	12 July 1967
14 March 1964	Adult	38°30'N 129°39'E	January 1965
4 November 1963	Adult	52°25'N 169°49'W	13 August 1965
31 October 1963	Adult	47°13'N 173°14'E	9 October 1965
8 November 1963	Adult	47°03'N 173°16'E	9 October 1965
8 November 1963	Adult	45°00'N 150°00'E	19 July 1967
9 December 1963	Adult	32°00'N 173°00'E	12 June 1968
14 November 1963	Adult**	46°50'N 124°00'W	1 July 1969

* Recaptured at Kure on 25 January 1965 and 16 January 1969 (breeding).

** Found breeding at Kure on 12 December 1964, 14 December 1965, and 16 January 1969.

LAYSAN ALBATROSS *Diomedea immutabilis*

Status

Abundant winter-spring breeder; 800 to 1,600 pairs annually. Present from early November until mid-August. Most abundant December-March. Breeding begins the third week of November and continues until mid-August.

Populations

All population estimates of Laysan Albatross prior to 1961 (Table LA-1) are considerably lower than POBSP estimates (Table LA-2), indicating an increase since 1923. Undoubtedly this increase resulted at least in part from the bulldozing of trails in 1959 and the construction of the LORAN station which increased the potential breeding habitat. Presently at least 50 percent of the population breeds in areas that were inaccessible to them prior to 1960.

The main source of the new breeders probably is Midway Atoll, 49 miles to the southeast. The Midway population was subjected to heavy human disturbance in the late 1950's and early 1960's and it is likely that this was also a factor in the population increase at Kure.

In three of the six breeding seasons that POBSP personnel worked on the island, accurate nest counts were made during the early part of the season; accurate nestling counts were obtained in all years. These data indicated an annual breeding population of 1,600 to 3,200 Laysan Albatross.

As with most species studied at Kure, studies of non-breeding Laysan Albatross were inadequate. Only two worthwhile studies of this type were conducted. In February and March 1965 large numbers of albatross were handled and painted according to their location on the island: north beaches, central roost, central plain, and the area south of the runway. It was hoped that subsequent ratios of painted to unpainted birds would yield information on the total number of Laysan Albatross using the island.

On six days during late February painted and unpainted birds were counted in the central roost. Using the following formula,

$$\frac{\text{Number painted observed}}{\text{Number unpainted and painted observed}} = \frac{\text{Total number painted}}{\text{Total population}},$$

the following "estimated populations" were obtained:

Date	Number Painted Observed	Number Unpainted Observed	% of Population Painted	Estimated Population
February 17	86	154	35.8	2,480
23	169	261	39.3	2,028
24	102	61	62.6	2,220
25	87	40	68.6	2,240
27	54	23	70.1	2,550
28	106	61	63.5	2,528

On 28 February the total population using the island was calculated to be 6,120. Since 3,279 adults were painted during February and an average 30 percent of those handled each time were unbanded, it is not unreasonable to assume this estimate was fairly accurate.

At the conclusion of the study 4,051 Laysan Albatross had been handled. During this time the maximum number of breeders was 1,070. Even if it is assumed that all breeders were handled, it still means that 73.6 percent of the total population using the island at least once were non-breeders.

From late January to mid-June 1969 an attempt was made each week to capture as many non-breeding Laysan Albatross as possible. Due to the large number of birds handled, two nights were necessary to complete this work. Breeding birds had been streamered previously to facilitate the separation of breeding from non-breeding albatross. Weekly counts (Table LA-3) showed that on the average 713 non-breeding Laysan Albatross roosted on the island each night during this study. At their peak of abundance these non-breeders composed 42-58 percent of the total population using the island. By late June 5,197 non-breeding Laysan Albatross had been handled. Since only 2,000 albatross were breeding, non-breeding Laysan Albatross composed at least 72 percent of the population that used Kure Atoll during the 1968-69 breeding season.

The composition of the non-breeding Laysan Albatross handled was as follows: 486 (9.4 percent) had bred previously at Kure, 943 (18.2 percent) were raised at Kure but had not bred yet, 727 (14.0 percent) had been banded at Kure as adults but had not been found breeding there, 339 (6.4 percent) were banded on other islands, and 2,702 (52.0 percent) were unbanded. Therefore, at least 58.4 percent of the non-breeding Laysans were probably of non-Kure origin and 27.6 percent were of definite Kure origin.

Annual Cycle

After an absence of almost two and one-half months, Laysan Albatross returned to the atoll in early November (earliest records: 4 November 1963, 5 November 1964, and 4 November 1968). The September 1918 record

Table LA-1. Previous records of Laysan Albatross on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	300	Scattered over island, main colony near middle of island (Munter, 1915: 137).
1918	September 15	?	Offshore (R.G. 45, Nat. Archives, Report of Commanding Officer U.S.S. Hermes to Commandant 14th Naval District).
1923	April 17-22	100	Young present; *ca.* 50 pairs nesting on sand beaches at edge of bushes, either alone or with colonies of Black-footed Albatross (Wetmore, ms.).
1956	December 9	?	Aerial count of 2,200 of both albatross species (Aldrich, *et al.*, ms.).
1957	June 5	805	270 nestlings counted; 75-100 adults present (Kenyon and Rice, 1958: 189).
1958	May 9	600+	Count of 300 chicks (Rice and Kenyon, 1962: 367).
1959	October 3-8	0	(Robbins, 1966: 53).
1960	March 28	425+	75 nesting pairs; 425 adults on island at one time (Robbins, 1966: 53).
1961	January 19-21	1,100+	550 nesting pairs; 700 adults on island at one time (Robbins, 1966: 53).
	September 12-14	0	(Udvardy and Warner, 1964).
1962	February 2-4	2,160+	1,080 nesting pairs (Robbins, 1966: 53).
	August 6-8	40+	20 nests (Robbins, 1966: 53).
1963	February 3-7	2,900+	1,450 nests (Robbins, 1966: 53).

Table LA-2. POBSP semi-monthly estimates of Laysan Albatross on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	3,600	4,000	-	1,450	-	5,000
16-31	-	4,900	4,000	-	-	-	5,000
February							
1-15	-	*	4,000	2,000	1,000+	-	5,000
16-28	*	4,500	6,120	-	-	-	6,000
March							
1-15	-	3,250	6,500	-	-	-	5,000
16-31	-	3,250	7,000	-	*	*	5,000
April							
1-15	-	3,200	4,500	-	-	-	3,500
16-30	-	3,000	1,500	1,300	-	-	3,000
May							
1-15	1,000	3,000	1,100	1,100	2,458	-	1,500
16-31	-	3,000	950	1,100	2,281	1,400	1,200
June							
1-15	-	3,000	950	990	2,209	1,220	1,000
16-30	-	1,250	950	955	2,133	1,200	*
July							
1-15	-	400	200	100	*	300	-
16-31	-	50	40	14	-	40	-
August							
1-15	-	14	4	2	-	4	-
16-31	-	0	-	0	-	2	-
September							
1-15	-	0	-	0	-	0	-
16-30	0	0	-	0	-	0	-
October							
1-15	0	0	-	-	-	0	-
16-31	0	0	-	-	-	0	-
November							
1-15	125	200	-	-	-	*	-
16-30	900	1,000	3,000	-	-	*	-
December							
1-15	3,450	4,000	4,500	-	-	*	-
16-31	3,600	4,000	-	1,450	-	*	-

* Birds present, number unknown.

Table LA-3. Counts of non-breeding Laysan Albatross, Green Island, Kure Atoll, 1969.

Date of Count		Number of Non-breeders	Percent of Total Population*
February	24-25	950	43.8
March	3 & 5	1,000	44.4
	10-11	1,250	52.1
	17-18	800	42.6
	24-25	850	44.0
	31- 1	1,400	58.3
April	11 & 14	1,250	55.4
	20-21	1,000	51.3
	29-30	850	47.2
May	5-6	865	47.7
	12 & 14	330	25.8
	20-21	415	30.4
	26	110	10.4
June	2-3	250	21.2
	9	70	7.0
	16	25	2.6

* Includes twice the number of nests and the number of non-breeders.

is unique. They were not numerous until late in the month and not until December was the population peak reached. By mid-April the population began to decrease, mainly due to the departure of non-breeders; by mid-June adults were rarely seen. By late August all Laysan Albatross had left the atoll.

Non-breeding Laysan Albatross were present from at least late December through June. They were most abundant, composing as much as 58 percent of the total population using the island, from at least January to mid-April.

Limited data showed the following periods of occurrence for various Laysan Albatross age classes: 4-year olds and 5-year olds--at least late January through June, 3-year olds--at least February to mid-May, and 2-year olds--from mid-March to early May. The first three age classes were most common in March and April, while the latter group was never common.

Laysan Albatross bred on a well-defined annual cycle, from mid-November to mid-August, which showed no significant yearly variation. Figure LA-1 shows the cycle for the 1964-65 breeding season when the most accurate data were collected.

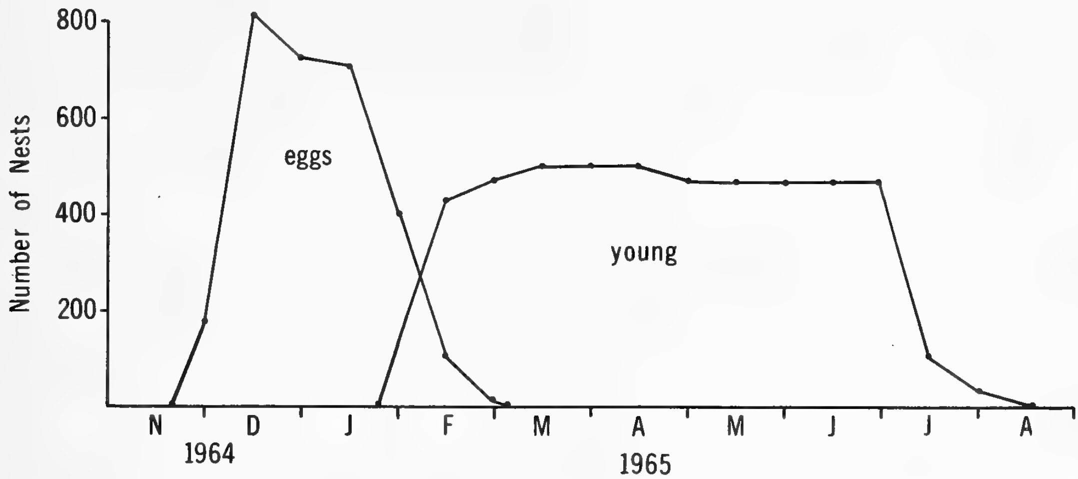

Figure LA-1. Breeding cycle of Laysan Albatross on Green Island, Kure Atoll, 1964-65.

The first egg was laid on 21 November in 1963, 20 November in 1964, 17 November in 1965, and 19 November in 1968. Eggs were laid until late December, with a peak in late November and early December. The eggs hatched 63 to 74 days ($\bar{x}$=66.9, n=15) after laying; the first eggs hatched on 25 January in 1964, 26 January in 1965, and 22 January in 1969. Peak hatching occurred the first two weeks of February. By the end of that month all eggs had hatched.

For 10 to 21 days ($\bar{x}$=15.7, n=23) after hatching at least one of the pair remained with the chick. Afterwards they returned only briefly to feed it. The fledging period for Laysan Albatross was 137 to 163 days ($\bar{x}$=150.5, n=8), thus, young albatross began to leave the atoll during the first week of July and all were gone by late August. Most birds fledged the first two weeks of July. Some of these young Laysan Albatross returned to the atoll for the first time ca. two years after hatching.

Nesting Success

Table LA-4 summarizes Laysan Albatross productivity from 1963 through 1969. The smaller number of young that fledged in 1965, and especially 1966, resulted from rat predation. In the latter year only one young fledged from the area northeast and east of the barracks. Sandstorms, which buried many nests, caused much nest loss in 1968-69.

Hatching success was determined for 25 nests in 1963-64 as 44 percent, for 25 nests in 1964-65 as 60 percent, and for 864 nests

in 1968-69 as 61.7 percent. Fledging successes for the respective years were 24 percent, 20 percent, and 48.3 percent of all eggs that were laid, and 54.6 percent, 33.3 percent, and 78.2 percent of eggs that hatched.

Table LA-5 summarizes the recapture of nestling Laysan Albatross in subsequent years. The low rates for the 1966, 1967, and 1968 cohorts reflect the tendency of younger Laysans to remain away from the atoll rather than low survival rates.

Ecology

Laysan Albatross bred in most of the open areas on the island, avoiding only the area around the barracks and, generally, the exposed open beaches where the similar Black-footed Albatross bred in largest numbers. They were also found in fairly dense *Scaevola* thickets and under *Tournefortia* where there was enough open area underneath to permit the adults to walk from the nest to an open area. The greatest number of nests was present in the central plain, along the runway, behind the fuel tanks and along the lagoon beach-*Scaevola* ecotone. Very few nests were found along the east beach. Figure LA-2 shows the general location of the breeding areas in May 1967; the sites were similar to those of previous years.

The single egg was laid on the ground. As incubation progressed the adults built a mound of vegetation around their bodies, thus forming a substantial nest.

The range of the non-breeders coincided with that of the breeders. Nests often became the focal point for roosting aggregation. Towards the end of the breeding season young Laysan Albatross began to form groups along the beaches where they made their first attempts to fly, often ending up in the lagoon and swimming back to shore.

Table LA-4. Productivity of Laysan Albatross on Green Island, Kure Atoll, 1963-69.

Breeding Season	Maximum Egg Count or Estimate	Maximum Nestling Count or Estimate	Approximate Number of Young Fledged	Percent Fledged from Maximum Number of Nests
1963-64	1,600	1,600	1,000	62.5
1964-65	841	475	470	55.8
1965-66	700	800[1]	475	52.6
1966-67	650	1,050	1,000	--
1967-68	--	701	600	--
1968-69	1,000	625	465	46.5

[1] Also 100 eggs (February 7-10), C.S. Robbins estimate.

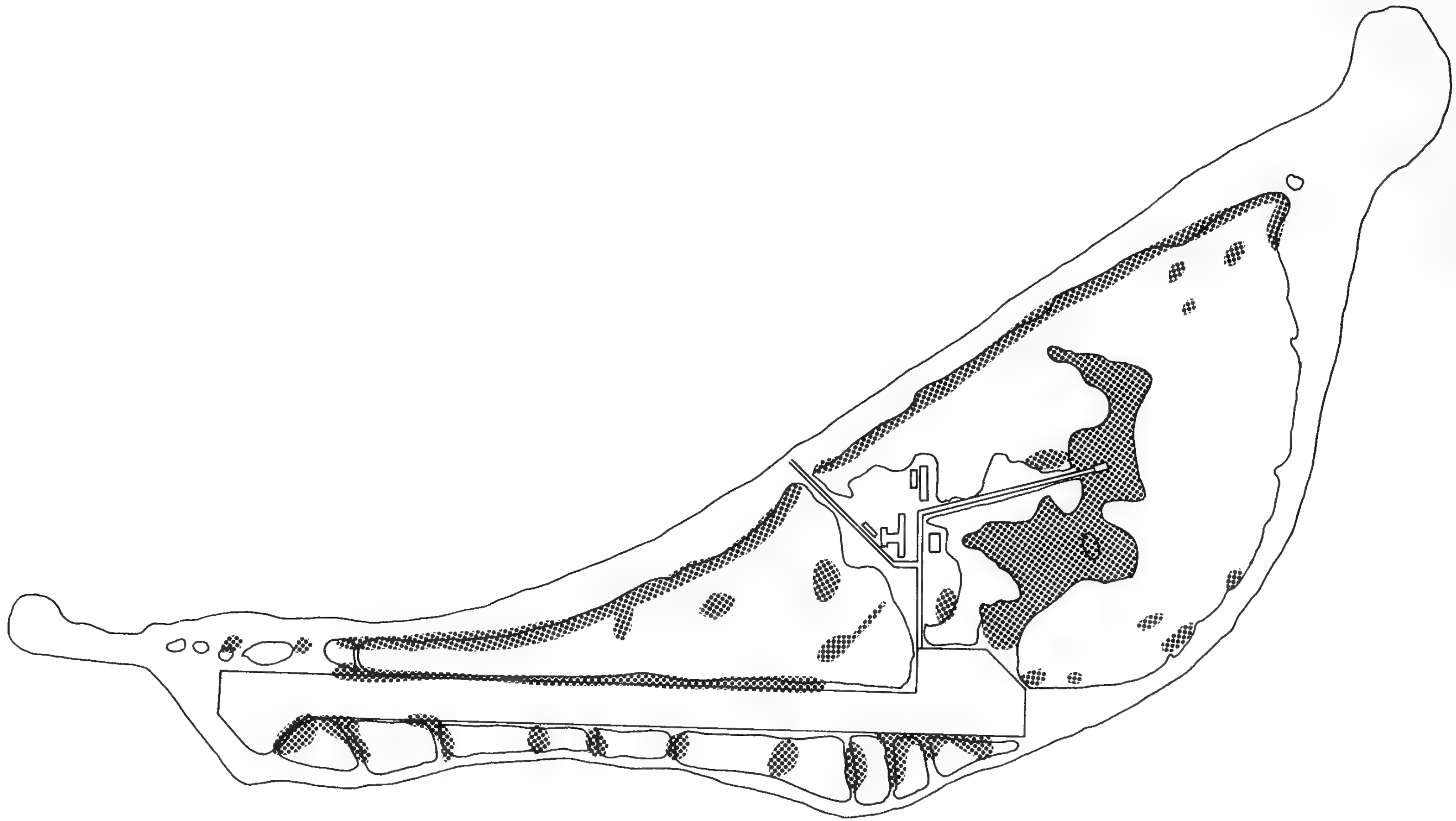

Figure LA-2. Distribution of breeding Laysan Albatross on Green Island, Kure Atoll, May 1967.

Table LA-5. Recapture rates of Laysan Albatross banded as nestlings at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1959-60	18	100.0	33.3 (0.0)	33.3 (0.0)	33.3 (0.0)	33.3 (27.8)	22.2 (16.7)	5.6 (5.6)	5.6 (0.0)	5.6 (0.0)	5.6 (5.6)
1960-61	252	--	100.0	38.5 (0.0)	38.5 (0.0)	38.5 (2.8)	35.3 (17.5)	26.2 (2.8)	23.8 (1.2)	23.4 (0.0)	23.4 (23.4)
1961-62	15	--	--	100.0	6.7 (0.0)	6.7 (0.0)	6.7 (0.0)	6.7 (0.0)	6.7 (0.0)	6.7 (0.0)	6.7 (6.7)
1963-64	938	--	--	--	--	100.0	53.9 (0.0)	53.9 (0.1)	53.6 (3.0)	53.6 (5.7)	52.8 (52.8)
1964-65	473	--	--	--	--	--	100.0	46.1 (0.0)	46.1 (0.4)	46.1 (0.2)	46.1 (46.1)
1965-66	657	--	--	--	--	--	--	100.0	24.1 (0.0)	24.1 (0.0)	24.1 (24.1)
1966-67	954	--	--	--	--	--	--	--	100.0	2.3 (0.0)	2.3 (2.3)
1967-68	701	--	--	--	--	--	--	--	--	100.0	0.0 (0.0)
1968-69	467	--	--	--	--	--	--	--	--	--	100.0

*First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Banding and Movements

From 1960 through 1969, 11,711 adult Laysan Albatross were banded at Kure Atoll. Tables LA-6 and 7 summarize the recapture rates of these birds in subsequent years at the atoll. These recapture rates are probably near the survival rates as large numbers of Laysan Albatross were handled, especially during the 1963-64, 1964-65, and 1968-69 breeding seasons (Table LA-8). As would be expected, a larger percentage of breeders than non-breeders were usually recaptured.

One hundred and four of these adult Laysan Albatross were captured on other islands: 100 at Midway Atoll, 2 at Pearl and Hermes Reef, 1 at Laysan, and 1 at French Frigate Shoals. Thirteen of the Midway birds and the Laysan bird were recaptured later at Kure.

From 1960 through 1969, 4,475 nestling Laysan Albatross were banded. The recapture of these birds has been discussed previously. One banded on 15 May 1964 was found dead on Eastern Island, Midway Atoll, in December 1967.

The recovery of Kure-banded Laysan Albatross at sea (Table LA-9) indicates a basic northeasterly post-breeding dispersal from the atoll.

One Laysan Albatross banded as an adult by POBSP personnel and 27 banded as nestlings on other islands were recaptured at Kure. The adult was from Midway Atoll and the nestlings were from the following locations: Midway Atoll (3), Pearl and Hermes Reef (21), Lisianski (1), and Laysan (2). None was found breeding.

In addition, 537 Laysan Albatross banded by non-POBSP personnel, mainly Harvey I. Fisher, Dale W. Rice, and Chandler S. Robbins, were captured at Kure. The majority (532) had been banded at Midway Atoll; 54 as adults and 478 as nestlings. Eleven of the adults and 55 of the nestlings were found breeding at Kure. The other Laysans were banded as nestlings: 1 at Pearl and Hermes Reef and 4 on Lisianski.

Table LA-6. Recapture rates of adult Laysan Albatross banded as breeders at Kure Atoll and recaptured there (expressed as percentages), 1960-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1960-61	396	100.0	81.6 (24.2)	77.5 (19.2)	75.5 (62.6)	49.2 (26.5)	39.4 (29.6)	20.7 (3.1)	18.7 (1.0)	18.7 (18.7)
1961-62	952	--	100.0	85.4 (23.1)	83.6 (70.8)	60.9 (30.5)	50.1 (39.1)	26.5 (6.6)	22.7 (0.7)	22.4 (22.4)
1962-63	750	--	--	100.0	84.8 (71.1)	61.2 (33.3)	46.8 (29.1)	28.9 (3.7)	27.5 (0.9)	27.1 (27.1)
1963-64	1,738	--	--	--	100.0	62.1 (32.8)	51.2 (37.9)	28.8 (6.6)	25.0 (0.9)	24.5 (24.5)
1964-65	48	--	--	--	--	100.0	47.9 (27.0)	31.3 (8.3)	27.0 (0.0)	27.0 (27.0)
1965-66	18	--	--	--	--	--	100.0	22.2 (0.0)	22.2 (0.0)	22.2 (22.2)
1968-69	274	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table LA-7. Recapture rates of adult Laysan Albatross banded as non-breeders at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1959-60	16	100.0	50.0 (0.0)	50.0 (6.3)	50.0 (6.3)	50.0 (31.3)	37.5 (31.3)	37.5 (25.0)	18.8 (0.0)	18.8 (6.3)	12.5 (12.5)
1963-64	2,417	--	--	--	--	100.0	63.2 (42.9)	52.1 (31.9)	30.3 (5.2)	27.5 (1.5)	26.5 (26.5)
1964-65	1,636	--	--	--	--	--	100.0	40.5 (18.8)	28.1 (6.7)	26.0 (1.0)	25.9 (25.9)
1965-66	656	--	--	--	--	--	--	100.0	27.6 (3.8)	25.5 (1.5)	24.7 (24.7)
1966-67	94	--	--	--	--	--	--	--	100.0	35.1 (3.2)	35.1 (35.1)
1967-68	16	--	--	--	--	--	--	--	--	100.0	12.5 (12.5)
1968-69	2,702	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table LA-8. Number of adult Laysan Albatross handled during several breeding seasons at Kure Atoll.

Breeding Season	Breeding	Non-breeding	Totals
1959-60	0	16	16
1960-61	396	0	396
1961-62	1,040	13	1,053
1962-63	1,030	24	1,054
1963-64	1,618	3,052	4,670
1964-65	359	3,787	4,146
1965-66	1,291	1,929	3,220
1966-67	342	294	636
1967-68	0	168	168
1968-69	1,317	5,197	6,514

Table LA-9. Laysan Albatross banded at Kure Atoll and recovered at sea.

Date Banded	Age at time of Banding	Where Found	When Found
20 January 1961	Breeding adult	32°00'N 173°00'E	March 1961
3 February 1962*	Breeding adult	27°45'N 130°10'E	26 April 1965
8 February 1962**	Breeding adult	42°00'N 144°00'E	2 August 1967
5 February 1963***	Breeding adult	42°30'N 169°20'E	10 September 1965
28 December 1963	Breeding adult	36°12'N 141°25'E	24 January 1964
26 January 1964	Adult	39°35'N 146°38'E	5 September 1964
14 March 1965	Adult	44°25'N 173°02'E	31 October 1965
26 March 1965	Adult	Marshall Islands: Mejit Atoll	20 May 1965
9 February 1965	Breeding adult	42°30'N 169°20'E	10 September 1965
9 December 1963	Adult	31°02'N 131°33'E	8 March 1967
30 March 1967	Adult	42°50'N 160°44'E	17 August 1967
21 January 1964	Breeding adult	42°11'N 155°18'W	25 July 1968
9 December 1963****	Breeding adult	21°50'N 159°20'W	10 March 1969
1 May 1961	Nestling	40°50'N 150°00'E	1 November 1962
29 July 1964	Nestling	43°19'N 155°27'E	27 July 1965
27 June 1967	Nestling	41°49'N 150°06'E	17 October 1967
15 May 1964	Nestling	36°09'N 143°46'E	10 December 1966

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* Recaptured at Kure 16 November 1963.

** Recaptured at Kure 27 December 1963 (breeding), 20 November 1964 and 30 November 1965 (breeding).

*** Recaptured at Kure 15 January 1964 (breeding).

**** Recaptured at Kure 14 December 1965 (breeding) and 4 December 1968 (breeding).

BLACK-FOOTED x LAYSAN ALBATROSS *Diomedea nigripes x immutabilis*

A hybrid albatross was collected on 26 January 1964. This individual, a female, resembled a Black-footed Albatross in plumage and bill size, but had a lighter-colored head than usual, a whitish abdomen, and a horn-colored bill similar to that of the Laysan.

NORTHERN FULMAR *Fulmarus glacialis rodgersii*

In 1964 four dead Fulmars were collected: one each on 16 January, 26 February, 28 March, and 30 March. These latter two birds were floating in the surf off the west point.

Only the January specimen, a dark-phase individual, was prepared as a study skin. The color phase of the others was not recorded.

Fulmars have been also recorded in the Northwestern Hawaiian Islands from Midway Atoll and French Frigate Shoals (Clapp and Woodward, 1968).

BONIN PETREL *Pterodroma h. hypoleuca*

Status

Abundant winter-spring breeder; maximum estimate 2,500. Present from early August to June. One July record. Peak populations present from September or October through mid-March. Breeds from late January to late June.

Populations

Munter (Table BP-1) probably overlooked Bonin Petrels during his brief diurnal stay, while Wetmore gave no numerical estimate so it is impossible to determine whether or not the Bonin Petrel population has changed numerically since the early part of this century. Robbins' October 1959 estimate, made prior to the alteration of the island, is in general agreement with recent POBSP ones (Table BP-2), suggesting that the LORAN station construction had little effect on the population size.

Recent POBSP estimates indicated a maximum of 2,000 to 2,500 individuals using the island during a two week period. These estimates, however, are considered unreliable and the total population may be considerably higher. For example, during the 1963-64 breeding season 1,620 Bonin Petrels, about 900 less than the highest estimate, were banded. The comparable figures for the next season were 1,005 and *ca.* 1,000, respectively. It is unlikely that 64 percent of the total population using the island in 1963-64, and 50 percent in 1964-65, were banded; these maximum estimates were probably too small.

Table BP-1. Previous records of Bonin Petrels on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	--	(Munter, 1915).
1918	September 15	?	Offshore (R.G. 45, Nat. Archives, Report of Commanding Officer U.S.S. <u>Hermes</u> to Commandant 14th Naval District).
1923	April 17-22	?	None found nesting (Wetmore, ms.).
1957	June 5	--	(Kenyon and Rice, 1958).
1959	October 3-8	1,000	(Robbins, 1966: 53).
1960	March 28	--	(Robbins, 1966: 53).
1961	January 19-21	500	(Robbins, 1966: 53).
	September 12-14	?	I [illegible]esting (Udvardy and Warner, 1964: 2).
1962	February 2-4	200	([illegible] 1966: 53).
	August 6-8	1	(Robbi[illegible] 53).
1963	February 3-7	10	(Robbins, [illegible]

Even more illustrative of the difficulty in estimating the size of Bonin Petrel populations was a roosting study conducted from 11 February to 14 April 1969 (details to be published elsewhere). On alternate nights at <u>ca</u>. 2100 hours as many Bonin Petrels as possible found roosting or burrowing in either the north antenna field or the open area just south of the barracks were captured. Unbanded individuals were banded and the band numbers of previously banded ones were recorded. During this study 1,747 different Bonin Petrels were handled; yet the maximum number handled on any single night was only 213. Obviously there was a considerable amount of turnover. Usually at least 90 percent of the birds captured on any night had not been handled the previous night nor on any other given night, and at least 40 percent had not been handled previously during the study period. Since only 451 Bonins were captured more than once, the Kure population was highly transitory. Based on an average daily total turnover rate of 50 percent, and a daily population of 100 birds from September through April, the total number of Bonin Petrels using Kure at least once would be 12,000. Figure BP-1 shows the number of Bonin Petrels captured each night during this study. This is a better indication of the size of the population than the semi-monthly estimates.

Table BP-2. POBSP semi-monthly estimates of Bonin Petrels on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	225	1,500	-	2,000	-	400
16-31	-	225	1,500	-	-	-	800
February							
1-15	-	*	1,500	2,500	2,500	-	2,000
16-28	-	2,500	1,500	-	-	-	2,500
March							
1-15	-	2,500	2,000	-	-	-	2,500
16-31	-	750	2,000	-	*	100	1,000
April							
1-15	-	750	200	-	-	-	500
16-30	-	750	100	150	-	-	250
May							
1-15	*	300	25	20	100	-	200
16-31	-	0	1	1	10	1	200
June							
1-15	-	0	0	0	1	0	100
16-30	-	0	0	0	0	0	-
July							
1-15	-	0	0	0	0	0	-
16-31	-	0	0	0	-	1	-
August							
1-15	-	0	40	50	-	1	-
16-31	-	50	-	200	-	500	-
September							
1-15	-	500	-	750	-	1,000	-
16-30	*	500	-	1,000	-	1,000	-
October							
1-15	*	500	-	-	-	*	-
16-31	*	1,000	-	-	-	*	-
November							
1-15	750	1,000	-	-	-	*	-
16-30	400	1,000	700	-	-	*	-
December							
1-15	400	1,500	1,000	-	-	*	-
16-31	500	1,500	-	2,000	-	*	-

* Birds present, number unknown.

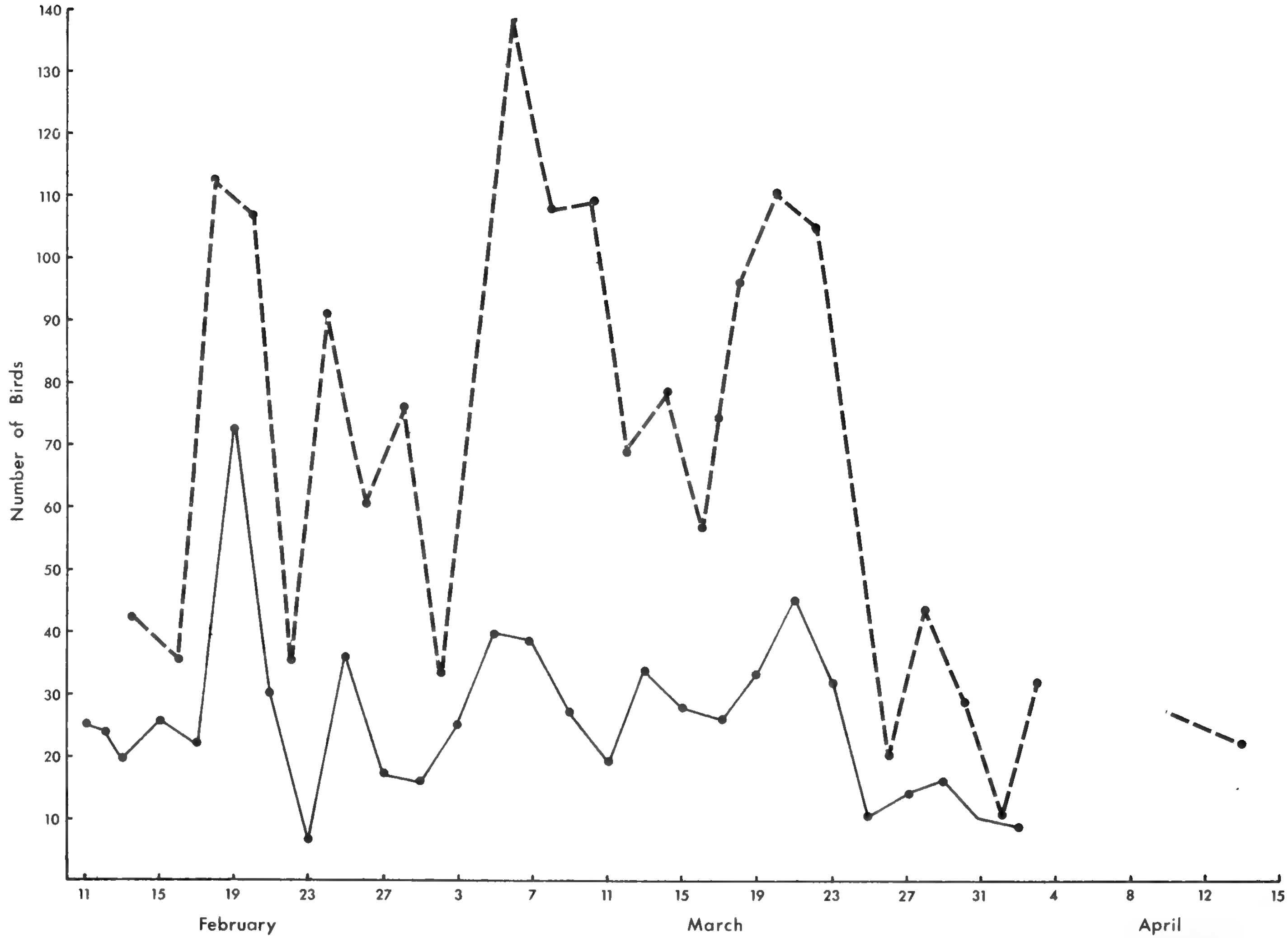

Figure BP-1. Number of Bonin Petrels captured each night in two study areas, 11 February-14 April 1969, on Green Island, Kure Atoll.

Since the maximum nest count was 500, most Bonin Petrels using the island were non-breeders, probably birds from other islands (see Banding and Movements). This would account, in part, for the relatively stable population size despite the almost complete breeding failure of this species.

Annual Cycle

Bonin Petrels returned to the atoll in early August (earliest records: 6 August 1962, 10 August 1965, and 8 August 1968). At first only a few individuals were present but by September or October they were abundant. Peak populations were present through mid-March. The size of the population then decreased rapidly and by May few petrels roosted on the island. Usually all birds had departed by late May (latest records: 24 May 1965, 25 May 1966, 4 June 1967, and 27 May 1968). In 1969, when young Bonins fledged, adults were present until at least mid-June). The July 1968 record is unique.

Although courting and burrowing began shortly after the adults returned, egg laying did not begin until late January (23 January 1964 and 1965 and ca. 17 January 1969). Apparently most eggs were laid in late January and early February. In 1969 a female with an egg in the oviduct was captured on 19 February. This was in accordance with the termination of egg laying for other years.

Eggs were known to have hatched only in 1969, when the first ones hatched in early March and the last ones in early April. Most eggs hatched from ca. 16 to 20 March. The first chicks fledged in early June and the last ones the third week of June. It is not known how many years will elapse before these young Bonin Petrels return to the atoll.

Nesting Success

From 1964 through 1968 no young Bonin Petrels were known to have fledged from the atoll. In 1968, however, one young may have been successfully reared, as on 17 July an adult was captured that regurgitated stomach oil when handled, a sign in most procellariiformes that young are present. A careful study of burrows in the area revealed no young.

The only success data were for 1969 when three study areas, one in the open area just south of the barracks, one in the north antenna field, and one in the south antenna field, were established in February. The former area was unprotected; the latter two areas were poisoned with Warfarin to protect them against Polynesian rats.

In the area near the barracks 20 nests were marked in mid-February. By 25 February they had all disappeared due to rat predation. The eggs had been broken and the shells were often found outside the burrow.

Four eggs of the 9 (44.4 percent) marked in the south antenna field hatched. Two of these young (50 percent) fledged.

In the north antenna field 24 of 40 (60 percent) marked eggs hatched and 10 of these chicks fledged (25 percent of all eggs and 41.7 percent of eggs that hatched). Rats destroyed a few of the nests and others were probably lost at the initial disturbance, but the cause of loss later in the year was unknown.

An estimated 80 young Bonin Petrels, all from the central plain, fledged in 1969. Most of these birds were outside the protected areas, so they were subjected to possible rat predation. Whether the poisoning program was sufficient to eliminate these mammals from the central plain, or whether the population was naturally reduced, is unknown, but the data from the study areas strongly suggest that Polynesian rats were the major factor in the breeding failure of this species at Kure Atoll.

Ecology

Bonin Petrels occurred mainly in the area just south of the barracks, the small antenna field by the tennis court, and at the northern edges of the north and south antenna fields.

The major breeding habitat was the sand-*Eragrostis* association. Here they dug burrows from one to six feet long, generally under a grass clump. Some birds, possibly young ones, dug shallow trenches, but these were not utilized for breeding. The single egg was laid near the far end of the burrow. Other burrows were found under *Scaevola* near the grassy areas, in the *Tribulus*-covered central plain, and in open areas of the central roost. Not all of the sand-*Eragrostis* area was used by this species. In 1969 the majority of young Bonin Petrels fledged from burrows along the edges of *Scaevola* at the northern end of the south antenna field.

Banding and Movements

Robbins banded 48 adult Bonin Petrels and the POBSP banded 6,050. The low recapture rates of these birds (Table BP-3) agree with the previous discussion of the large amount of turnover in this species. Eighty nestling Bonin Petrels were banded in 1969.

Since Bonin Petrels burrow and when they are roosting on land their legs are in almost constant contact with the ground, bands are subjected to heavy abrasion. After three years or so the bands become so thin they fall off. Thus recaptures after three years are lower than would be expected.

Three Kure-banded Bonin Petrels were recaptured at Pearl and Hermes Reef: an adult banded on 10 March 1965 was recaptured on Seal

Table BP-3. Recapture rates of Bonin Petrels banded as adults at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Breeding Season Banded	n.	Breeding Season Recaptured 1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
1959-60	38	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1960-61	1	--	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1961-62	9	--	--	100.0	33.3 (0.0)	33.3 (11.1)	22.2 (0.0)	22.2 (0.0)	22.2 (22.2)	0.0 (0.0)	0.0 (0.0)
1963-64	1,620	--	--	--	--	100.0	15.2 (3.7)	11.9 (2.8)	9.5 (4.6)	5.9 (0.6)	5.9 (5.9)
1964-65	1,005	--	--	--	--	--	100.0	15.8 (2.9)	13.6 (7.8)	7.7 (0.0)	7.7 (7.7)
1965-66	391	--	--	--	--	--	--	100.0	43.2 (27.4)	22.8 (0.0)	22.8 (22.8)
1966-67	941	--	--	--	--	--	--	--	100.0	13.7 (0.0)	13.7 (13.7)
1968-69	1,598	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Island 8 days later and then captured at Kure on 23 November 1965; another adult banded on 23 November 1964 was recaptured on Seal Island on 19 March 1965; and an adult banded on 21 October 1964 was captured on Southeast Island on 16 March 1965.

Twelve non-breeding Bonin Petrels banded on other islands were recaptured at Kure (Table BP-4).

Table BP-4. Adult Bonin Petrels banded on other islands and recaptured at Kure Atoll.

Place of Banding	Date of Banding	Date of Recapture
Midway Atoll	29 March 1960	3 October 1964
Midway Atoll	5 February 1962	30 November 1964
Midway Atoll	6 February 1962	8 February 1966
Midway Atoll	7 December 1963	9 September 1966
Midway Atoll	17 December 1963	15 September 1966
Pearl and Hermes Reef	16 March 1965	10 September 1966
Pearl and Hermes Reef	7 March 1963	11 February 1966
Pearl and Hermes Reef	1 March 1963	8 January 1965
Lisianski	12 March 1965	25 February 1969
Lisianski	12 March 1965	13 March 1969
Lisianski	13 March 1965	23 April 1969
French Frigate Shoals	12 March 1967	27 August 1968

KERMADEC PETREL — *Pterodroma neglecta*

On the evening of 20 April 1923 Wetmore collected a male, dark-phase Kermadec Petrel as it flew over the central plain. Another bird, possibly this species or the similar Herald Petrel (*Pterodroma armonjoniana heraldica*), was seen flying over Green Island on 31 July 1964. Wirtz described this individual as follows: "size and build of a tropicbird, lighter brown on back than a Wedge-tailed Shearwater, very sharp brown to white demarcation line on breast like Brown Boobies, rest of underparts very white, white underwings."

Kermadec Petrels occur commonly at sea in the central Pacific.

MURPHY'S PETREL — *Pterodroma ultima*

Ludwig collected a female Murphy's Petrel on 7 October 1963 as it flew over the central plain.

Murphy's Petrels have also been recorded in the Northwestern Hawaiian Islands at French Frigate Shoals (Clapp and Woodward, 1968).

BULWER'S PETREL *Bulweria bulwerii*

On 11 September 1964 DuMont saw a small all-dark bird with a wedge-shaped tail and a light band across the upper wing surface gliding over *Scaevola*. DuMont acknowledged that this individual may have been a young Brown Noddy rather than a Bulwer's Petrel; hence, the occurrence of this species at Kure is considered hypothetical.

WEDGE-TAILED SHEARWATER *Puffinus pacificus*

Status

Abundant summer-fall breeder; 500-1,000 pairs annually. Present from March to early December with peak populations from April through October. Breeding begins in June and continues through early December.

Populations

Estimating the size of the Wedge-tailed Shearwater population was difficult, not only because of their fossorial and nocturnal habits, but also because they bred under the dense *Scaevola*. Most estimates were based on the observer's judgment or on banding data, rather than on any consistent sampling. However, in 1967 and 1968 a method was utilized that allowed comparison of the population size on a weekly and yearly basis. Once a week, after dark, Wedge-tailed Shearwaters were counted in the central plain and the major breeding area south of the barracks. It was assumed that this number represented about 10 percent of the total population. This estimate took into account the larger area where the species occurred, the presence of undetected birds in burrows, and daily turnover.

During 1964, 2,481 adults were banded. If this species was similar to the other procellariiformes on the island, the total population using the island each year was at least twice this figure. A Lincoln Index calculation also suggested that the population size was at this level. In 1965, 173 of the 404 Wedge-tails handled had been banded in 1964 as birds in adult plumage, thus:

$$\frac{173}{404} = \frac{2{,}481}{x} \quad \text{where } x = \text{total population.}$$

Therefore, x = 5,794. Thus POBSP observations indicated a total yearly population of 5,000-6,000 individuals using the island. An estimated 1,000 to 2,000 Wedge-tails bred each year. Data are inadequate to determine how many of the non-breeding birds using the island were Wedge-tails that had bred previously at Kure or were subadults raised at Kure that had not bred yet.

The majority of the Kure population was light-phased. Only one adult of 137 (0.73 percent) handled in 1967 was a dark-phase morph.

Comparable figures for 1968 and 1969 were 0.69 percent and 0.43 percent, respectively. Only 19 dark-phase birds (out of 4,319) were banded by the POBSP.

Comparison of earlier observations (Table WTS-1) with POBSP estimates (Table WTS-2) is of limited value, but the available data tend to indicate no significant change in the size of the population during this century. The major breeding area was always in the central plain, an area that was not greatly altered by the construction of the LORAN station. Whether more Wedge-tails breed under Scaevola now than in 1923 is not known.

Table WTS-1. Previous records of Wedge-tailed Shearwaters on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	--	(Munter, 1915).
1923	April 17-22	300	Calling and burrowing (Wetmore, ms.).
1957	June 5	common	Numerous burrows (Kenyon and Rice, 1958: 189).
1959	October 3-8	5,000	Young (Robbins, 1966: 53).
1960	March 28	common	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	Hundreds of burrows (Udvardy and Warner, 1964: 2).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	1,000	(Robbins, 1966: 53).
1963	February 3-7	0	(Robbins, 1966: 53).

Annual Cycle

Wedge-tailed Shearwaters were first seen flying over the island on 2 March 1964, 19 March 1965, and 17 March 1969. The population increased in size rapidly and by the end of March hundreds were present. Apparently the largest populations were present from April through October. The 1967 and 1968 counts (Fig. WTS-1) suggested that Wedge-tails occurred on the island most commonly prior to egg laying and

Table WTS-2. POBSP semi-monthly estimates of Wedge-tailed Shearwaters on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	0	-	-	-	0
16-31	-	0	0	-	-	-	0
February							
1-15	-	0	0	0	0	-	0
16-28	0	0	0	-	-	-	0
March							
1-15	-	300	0	-	-	-	0
16-31	-	1,750	300	-	*	25	1,000
April							
1-15	-	3,500	1,000	-	-	-	5,000
16-30	-	3,500	1,000	750	-	-	5,000
May							
1-15	*	3,500	1,500	1,000	3,300	-	5,000
16-31	-	2,500	2,000	1,750	3,960	3,990	5,000
June							
1-15	-	2,500	2,000	1,750	2,330	1,260	5,000
16-30	-	2,500	2,000	1,750	2,070	1,140	*
July							
1-15	-	2,000	2,000	1,800	*	4,080	-
16-31	-	2,000	2,000	2,000	-	6,230	-
August							
1-15	-	2,000	2,000	2,500	-	3,790	-
16-31	-	2,000	-	2,000	-	5,410	-
September							
1-15	-	2,000	-	2,000	-	2,440	-
16-30	*	2,000	-	2,000	-	3,530	-
October							
1-15	*	3,000	-	-	-	*	-
16-31	*	3,000	-	-	-	*	-
November							
1-15	750	3,000	-	-	-	*	-
16-30	75	50	800	-	-	*	-
December							
1-15	*	0	1	-	-	*	-
16-31	0	0	-	0	-	0	-

* Birds present, number unknown.

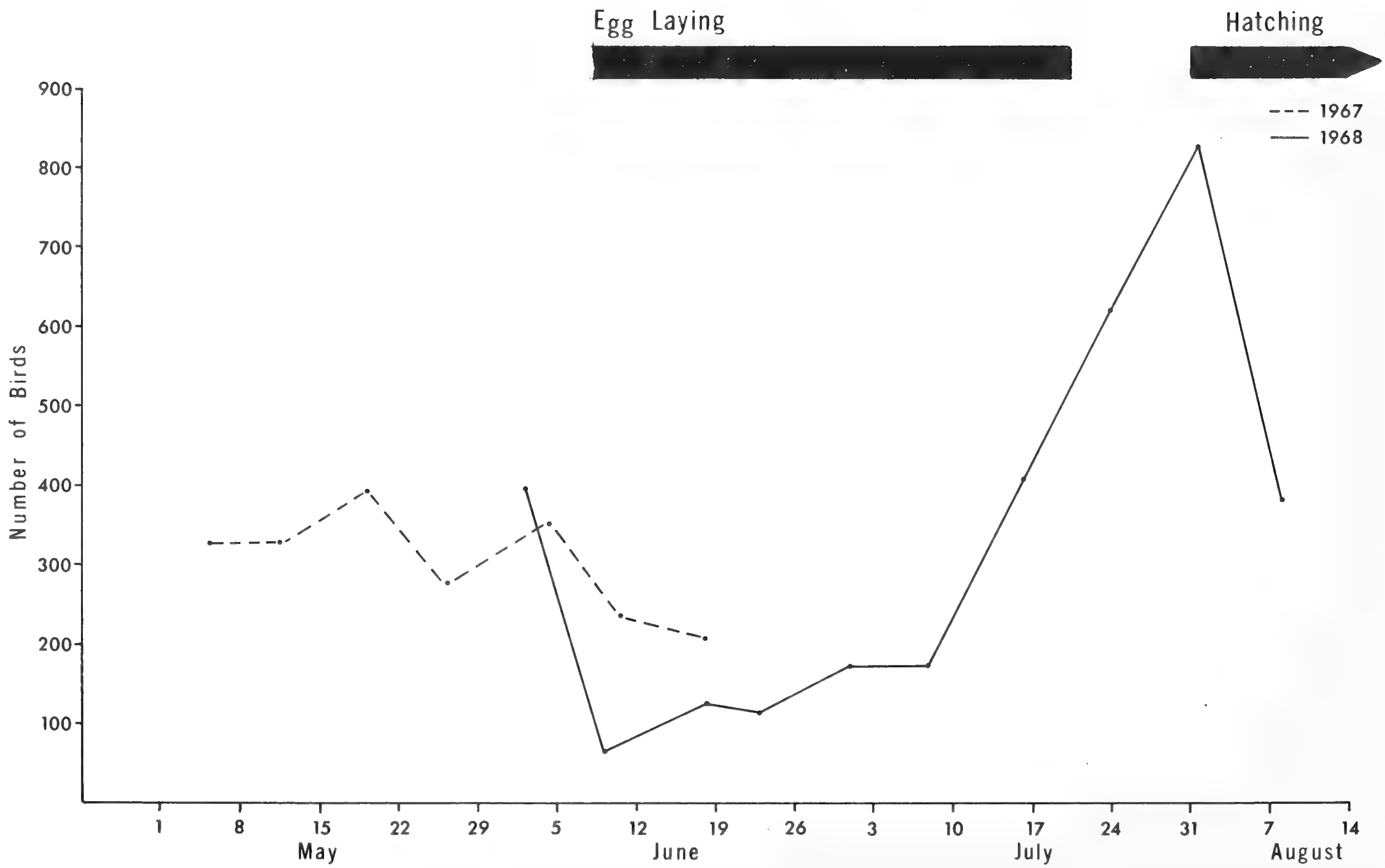

Figure WTS-1. Counts of Wedge-tailed Shearwaters in the central plain on Green Island, Kure Atoll, 1967-68.

hatching, and least commonly during the incubation period. By November the population began to decrease and all Wedge-tails had left by the middle of December.

Although courting and burrowing began shortly after the adults returned to the island, egg laying did not begin until June (11 June 1965, 17 June 1966, 8 June 1967, 18 June 1968, and 12 June 1969). Evidently peak egg laying occurred the last two weeks of June and in early July. Some eggs were probably laid as late as the third week of July. No yearly differences in the timing of peak egg laying were evident.

The first nestlings were found on 31 July 1964, 30 July 1965, early August 1966, and 9 August 1968. Hatching continued at least through August. Young Wedge-tails began to fly 99 to 111 days ($\bar{x}$=103, n=10) after hatching. Thus fledging began in late October and was completed by early December. Young Wedge-tailed Shearwaters did not return to the atoll until they were _ca_. 2 years old.

Nesting Success

In 1964 50 nests with one egg each were studied to determine hatching and fledging success. Forty-seven eggs (94 percent) hatched and 40 nestlings fledged (80 percent of all eggs laid and 85.1 percent of the eggs that hatched). Seven nestlings died before fledging. One was killed by an adult during defense of its nest, one was abandoned, and the remaining five were suspected victims of rat predation.

In some years hatching success may be considerably lower. For example, in August 1968 only 11 of 178 (6.2 percent) active Wedge-tailed Shearwater burrows checked in the central plain contained eggs or chicks. Whether all these burrows once had eggs which were destroyed, or whether only a small number of the burrows were utilized by this species, was not determined, but it suggests that nest loss may be heavy. Broken eggs with typical rat openings at the ends were commonly found in the central plain.

An estimated 1,000 young in 1964 and 400 in 1965 fledged.

Ecology

Wedge-tailed Shearwaters bred mainly in the central plain and in the grassy area just south of the barracks. Here they dug burrows, generally at the base of _Eragrostis_ or other vegetation. Some burrows were also found under _Scaevola_.

Other Wedge-tails laid their egg on top of the ground under _Scaevola_, where little or no direct sunlight penetrated. Generally the egg was placed in a shallow trench rather than on flat ground. Sixty nests of this type were found from 24 to 28 June 1967, indicating that they were not uncommon. They were found wherever there was a continuous growth of _Scaevola_ but appeared to be more common in the north roost.

When they were not at sea, in burrows, or flying over the island, Wedge-tails roosted in the same areas where they bred and along the beach-Scaevola ecotone.

Banding and Movements

Robbins banded 235 adult Wedge-tailed Shearwaters and the POBSP banded 4,319. The percentage of these birds recaptured at Kure was relatively small (Table WTS-3). In some years (e.g., 1967 and 1968) little effort was expended in capturing this species, resulting in lower recapture rates, but even in years when large numbers were handled (e.g., 1964, 1965, 1969), they were low, suggesting a high rate of turnover. An adult Wedge-tailed Shearwater banded the night of 12-13 March 1964 was recaptured the next night on Southeast Island, Pearl and Hermes Reef, 135 nautical miles to the southeast.

Three hundred and seven nestling Wedge-tailed Shearwaters were banded (4 in 1959, 5 in 1963, 237 in 1964, 57 in 1965 and 4 in 1966). Three of the 1964 cohorts were recaptured in subsequent years at Kure: 1 on 23 July 1966, 1 on 5 September 1966, and 1 on 31 July 1968.

Four Wedge-tails banded as adults on other islands were captured at Kure. One banded at Kilauea Point, Kauai, on 17 August 1964 was recaptured on 23 September 1964 and another one banded there on 26 March 1964 was captured on 5 September 1966. Two banded at French Frigate Shoals, one on 8 August 1964 and one on 19 June 1966, were recaptured on 19 November 1965 and 29 August 1966 respectively.

SOOTY SHEARWATER *Puffinus griseus*

The remains of eight Sooty Shearwaters were found on Green Island: 1 on 18 May 1965, 1 on 23 April 1966, 2 on 4 May 1966, 2 on 28 May 1966, 1 on 26 May 1968, and 1 on 29 May 1969. Five of these birds washed up on the lagoon beach and three on the ocean beach.

On 19 May 1966 Woodward captured a Sooty Shearwater with extremely worn flight feathers as it swam in the lagoon.

Sooty Shearwaters are regular migrants through the central Pacific.

CHRISTMAS SHEARWATER *Puffinus nativitatis*

Status

Uncommon spring-summer breeder; *ca.* 25 pairs annually. Present from March through October. Breeds from late April until October.

Table WTS-3. Recapture rates of Wedge-tailed Shearwaters banded as adults at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	157	100.0	0.6 (0.0)	0.6 (0.0)	0.6 (0.0)	0.6 (0.0)	0.6 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1962	78	--	--	--	100.0	33.3 (0.0)	33.3 (30.1)	2.5 (1.3)	1.3 (1.3	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1963	196	--	--	--	--	100.0	17.9 (0.0)	17.3 (12.3)	6.1 (5.1)	1.0 (1.0)	0.0 (0.0)	0.0 (0.0)
1964	2,481	--	--	--	--	--	100.0	19.5 (7.0)	9.7 (8.1)	2.3 (1.3)	0.7 (0.2)	0.5 (0.5)
1965	206	--	--	--	--	--	--	100.0	8.3 (5.3)	3.4 (0.5)	2.9 (1.9)	1.0 (1.0)
1966	450	--	--	--	--	--	--	--	100.0	11.3 (3.6)	8.9 (1.3)	7.6 (7.6)
1967	108	--	--	--	--	--	--	--	--	100.0	9.3 (2.8)	6.5 (6.5)
1968	177	--	--	--	--	--	--	--	--	--	100.0	7.9 (7.9)
1969	701	--	--	--	--	--	--	--	--	--	--	--

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Populations

Robbins banded four adult Christmas Shearwaters and estimated the population as 125 in October 1959 (Table CS-1). This represented the first known record for the atoll. Since there was little habitat change from 1923 to 1959 it is probable that Wetmore overlooked this species in 1923. This is not surprising, due to the small population and secretive nature of Christmas Shearwaters. POBSP estimates are given in Table CS-2.

Fairly accurate population data were collected for three years. In 1967 four nests and 15 additional nest sites were located, indicating a breeding population of at least 38. One year later, between late May and mid-August, 48 different Christmas Shearwaters, two nests, and at least 23 potential nest sites were found. In 1969 12 nests, 12 nest sites, and 52 adults were located. Thus, if this species was similar to other procellariiformes on the island, the total population was at least twice the number of potential breeding birds, or 76 in 1967 and 100 in 1968 and 1969.

The Lincoln Index can be used for an approximation of the total population using the island. Nine of the 42 adults banded in 1968 were recaptured in 1969. An additional 39 adults were banded and 4 banded in 1967 were recaptured. Thus,

$$\frac{9}{51} = \frac{42}{x} \quad \text{where } x = \text{total population.}$$

Therefore, x = 238. This figure is not unreasonable as almost 25 percent of the estimated population was handled in both 1968 and 1969 and a considerable number of adults were unbanded in 1969.

In summary, the total Christmas Shearwater population using the island was 100 to 200, with ca. 25 pairs breeding annually.

Table CS-1. Previous records of Christmas Shearwaters on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	--	(Munter, 1915).
1923	April 17-22	0	(Wetmore, ms.).
1957	June 5	--	(Kenyon and Rice, 1958).
1959	October 3-8	125	4 adults banded (Robbins, 1966: 53).
1960	March 28	--	(Robbins, 1966: 53).

Table CS-1. (continued)

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	(Udvardy, 1961: 46).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	0	(Robbins, 1966: 53).
1963	February 3-7	0	(Robbins, 1966: 53).

Annual Cycle

Christmas Shearwaters were first seen on 11 March 1964, 15 March 1965, and 11 March 1969 after an absence of almost four and one-half months. By the end of the month most of the population was present. The population peak was maintained through at least mid-September. The population decreased as the young fledged and by late October all Christmas Shearwaters had left the atoll.

A breeding cycle was constructed from data from the 30 known nests (2 in 1963, 3 in 1964, 3 in 1965, 3 in 1966, 4 in 1967, 3 in 1968, and 12 in 1969). Data were inadequate to detect yearly variations.

Egg laying occurred from late April (earliest record: 26 April 1964) through at least May, hatching from mid-June to mid-July, and fledging from late September to late October (latest nestling records: 25 October 1964 and 28 October 1968). The limited data suggested an egg-laying peak in early or mid-May.

Ecology

Figure CS-1 shows the approximate location of Christmas Shearwater nests found on the island. The majority (59.3 percent) was located under Scaevola south of the barracks, suggesting that this was their center of abundance, or at least that nests were found most easily there. The single egg was placed on leaf-covered ground, under dense Scaevola, Scaevola-Ipomoea tangles, or Boerhavia-covered Scaevola. Here little or no direct sunlight reached the incubating adult. In 1967 four nests were under Scaevola, an average of eight feet from an open area.

In 1968 the abundance center of Christmas Shearwaters shifted from the area south of the barracks to a path just north of the transmitter building. The cause of this shift was unknown but may have been correlated with the increasing abundance of Verbesina, and consequent

Table CS-2. POBSP semi-monthly estimates of Christmas Shearwaters on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	0	-	-	-	0
16-31	-	0	0	-	-	-	0
February							
1-15	-	0	0	0	0	-	0
16-28	0	0	0	-	-	-	0
March							
1-15	-	25	5	-	-	-	1
16-31	-	100	100	-	-	25	60
April							
1-15	-	100	100	-	-	-	150
16-30	-	100	100	100	-	-	150
May							
1-15	5	100	100	100	75	-	150
16-31	-	100	100	100	75	100	150
June							
1-15	-	100	100	100	75	100	150
16-30	-	100	100	100	75	100	*
July							
1-15	-	100	100	100	*	100	-
16-31	-	100	100	50	-	100	-
August							
1-15	-	100	100	50	-	*	-
16-31	-	100	-	25	-	*	-
September							
1-15	-	100	-	*	-	*	-
16-30	*	100	-	0	-	*	.
October							
1-15	*	*	-	-	-	*	-
16-31	*	10	-	-	-	*	-
November							
1-15	0	0	-	-	-	0	-
16-30	0	0	0	-	-	0	-
December							
1-15	0	0	0	-	-	0	-
16-31	0	0	-	0	-	0	-

* Birds present, number unknown.

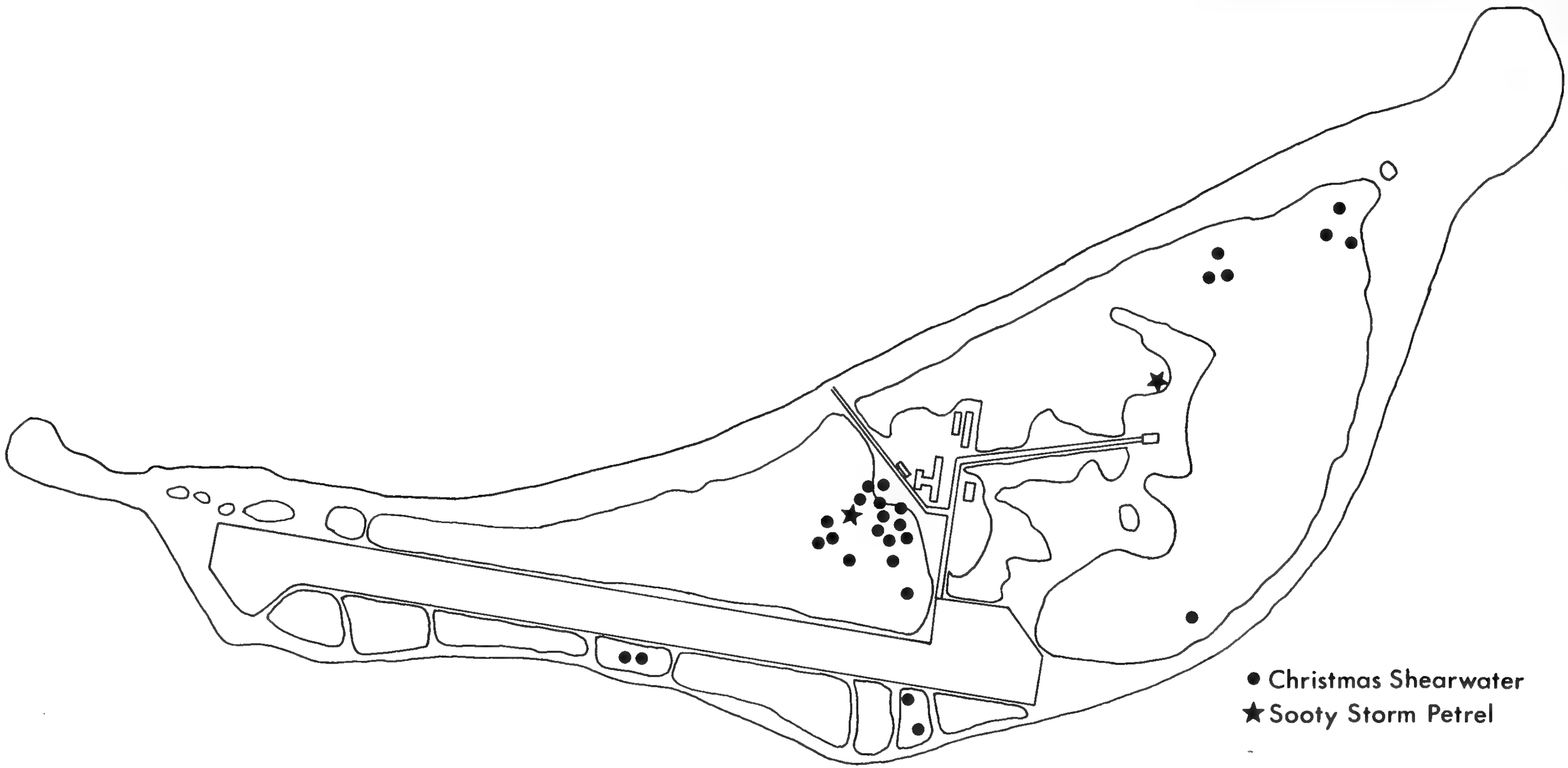

Figure CS-1. Distribution of breeding Christmas Shearwaters and Sooty Storm Petrels on Green Island, Kure Atoll.

decrease in available roosting sites, where the birds were formerly abundant. By 1969, however, they were again common south of the barracks.

Christmas Shearwaters roosted at the edge of Scaevola in the interior, along the beach, and in open areas along the runway.

Banding and Movements

One hundred and sixty-four adult Christmas Shearwaters were banded. Table CS-3 summarizes the recapture of these birds at the atoll in subsequent years. These figures suggest a high rate of turnover on the island, especially for 1967 through 1969 when a large percentage of the population was handled. The lack of any Christmas Shearwaters banded prior to 1967 captured in 1969 is probably the result of band loss. In this species as in the preceding one, bands wear away after three years or so.

Five nestling Christmas Shearwaters were banded (2 in 1963, 2 in 1964, and 1 in 1968). None was recaptured.

LEACH'S STORM PETREL Oceanodroma leucorhoa

On 10 May 1964 Wislocki found a Leach's Storm Petrel washed up on the beach. Another dead one was found on 21 December 1964 by Stadel.

Leach's Storm Petrels occur commonly at sea in the central Pacific.

SOOTY STORM PETREL Oceanodroma tristrami

Status

Uncertain; probably rare breeder. Few individuals present from October through mid-May, but no eggs or nestlings found.

Populations

The first recorded Sooty Storm Petrel for the atoll was an adult collected on 1 January 1964. Since that time POBSP observers found them irregularly in small numbers (Table SSP-1). POBSP data indicated a yearly population of perhaps 20 individuals. Earlier observers probably overlooked this species.

Annual Cycle

Sooty Storm Petrels arrived in late October or early November (earliest records: 31 October 1968 and 2 November 1964) and departed by mid-May (latest record: 14 May 1967). At least a few individuals were found in every month between these two dates.

Table CS-3. Recapture rates of Christmas Shearwaters banded as adults at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	4	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1962	1	--	--	--	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1963	4	--	--	--	--	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1964	35	--	--	--	--	--	100.0	17.1 (14.3)	5.7 (5.7)	5.7 (5.7)	0.0 (0.0)	0.0 (0.0)
1965	13	--	--	--	--	--	--	100.0	15.4 (7.7)	7.7 (7.7)	0.0 (0.0)	0.0 (0.0)
1966	14	--	--	--	--	--	--	--	100.0	28.6 (28.6)	0.0 (0.0)	0.0 (0.0)
1967	12	--	--	--	--	--	--	--	--	100.0	25.0 (0.0)	25.0 (25.0)
1968	42	--	--	--	--	--	--	--	--	--	100.0	21.4 (21.4)
1969	39	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Although no eggs or young were found, the evidence indicated that a few pairs bred. Burrowing was noted on 1 January 1964, 2 April 1964, and 5 November 1964, while storm petrels calling from burrows were heard in late December 1966, early January 1967, and 14 May 1967. In addition, 5 of the 7 (71.5 percent) collected individuals had enlarged gonads.

Ecology

Sooty Storm Petrels had the most restricted range of all species occurring regularly at the atoll (Fig. CS-1). The vegetation within the range was mainly Eragrostis, Boerhavia, and Solanum at the edge of Scaevola. At least 12 of the 20 adults banded were near Eragrostis.

In January and May 1967 this species was heard calling from Bonin Petrel burrows about four feet long, which were located under Scaevola ca. 4 feet from the edge of the grassy area south of the barracks. On 5 November 1964 a Sooty Storm Petrel was found digging under Solanum.

Banding and Movements

The POBSP banded 20 Sooty Storm Petrels (11 during the 1963-64 breeding season, 6 in the 1964-65 season, 1 the following season, and 2 in 1969). None has been recaptured.

RED-TAILED TROPICBIRD Phaëthon rubricauda

Status

Abundant late winter-summer breeder; ca. 1,000 pairs annually. Recorded in every month but essentially absent from December through mid-February. Most abundant from April to August. Although nests have been found in every month, the main breeding season extends from March through November.

Populations

Despite their conspicuousness and abundance, Red-tailed Tropicbirds were difficult to enumerate, due mainly to the difficulty of locating all their nests under Scaevola. POBSP estimates (Table RTTB-1) are based on an extrapolation from a study area at the west end of the runway for the number of nests present, and on the maximum number of tropicbirds counted in flight over the whole island at 1400 hours (these birds were non-breeders). In June 1967 to test the validity of the estimates approximately 60 percent of the island, mainly the northern half and sections of the southern end, was surveyed for tropicbird nests. At this time 658 nests were counted. A projection for the remainder of the island gave a total of 1,000 to 1,100 nests at the height of the breeding season; this agreed with estimates made in 1964 and 1965.

There was some apparent yearly fluctuation in the size of the breeding population although its exact magnitude was unknown. From 1965

Table SSP-1. POBSP semi-monthly estimates of Sooty Storm Petrels on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	2	0	-	20	-	0
16-31	-	10	0	-	-	-	0
February							
1-15	-	1	0	0	1	-	0
16-28	-	0	0	-	-	-	1
March							
1-15	-	1	0	-	-	-	1
16-31	-	0	0	*	0	0	0
April							
1-15	-	3	0	-	-	-	0
16-30	-	0	0	1	0	-	0
May							
1-15	-	0	0	0	10	-	0
16-31	-	0	0	0	0	0	0
June							
1-15	-	0	0	0	0	0	0
16-30	-	0	0	0	0	0	0
July							
1-15	-	0	0	0	0	0	-
16-31	-	0	0	0	-	0	-
August							
1-15	-	0	0	0	-	0	-
16-31	-	0	-	0	-	0	-
September							
1-15	-	0	-	0	-	0	-
16-30	0	0	-	0	-	0	-
October							
1-15	0	0	-	-	-	0	-
16-31	0	0	-	-	-	2	-
November							
1-15	0	4	-	-	-	10	-
16-30	0	1	0	-	-	5	-
December							
1-15	0	1	1	-	-	0	-
16-31	0	0	-	20	-	0	-

* Birds present, number unknown.

Table RTTB-1. POBSP semi-monthly estimates of Red-tailed Tropicbirds on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	5	7	-	5	-	5
16-31	-	8	6	-	-	-	6
February							
1-15	-	60	30	20	7	-	7
16-28	*	225	300	-	-	-	40
March							
1-15	-	500	200	-	-	-	200
16-31	-	1,000	400	-	450	175	1,200
April							
1-15	-	1,100	900	-	-	-	1,200
16-30	-	1,350	1,000	750	-	-	1,200
May							
1-15	2,000	1,350	1,800	1,000	2,000	-	1,200
16-31	-	1,350	2,200	1,400	2,000	1,244	1,200
June							
1-15	-	1,350	2,200	2,500	2,000	1,295	1,000
16-30	-	1,350	2,200	2,200	2,000	1,295	*
July							
1-15	-	1,500	1,600	2,200	2,000	1,095	-
16-31	-	1,500	1,400	2,200	-	1,095	-
August							
1-15	-	1,200	1,200	2,000	-	*	-
16-31	-	1,000	-	2,000	-	*	-
September							
1-15	-	800	-	1,000	-	*	-
16-30	*	500	-	350	-	*	-
October							
1-15	*	900	-	-	-	*	-
16-31	*	500	-	-	-	*	-
November							
1-15	75	150	-	-	-	*	-
16-30	8	15	18	-	-	*	-
December							
1-15	11	10	5	-	-	*	-
16-31	8	7	-	5	-	*	-

*Birds present, number unknown.

through 1968 the southwestern-most clump of Scaevola was checked regularly for tropicbird nests. In 1965 there were 97 nests; in 1966, 119; in 1967, 118; and in 1968, 109. These data suggest some minor variations, but no significant changes.

Previous estimates (Table RTTB-2) suggest that Red-tailed Tropicbirds were always common at Kure, but that the population probably increased after the construction of the LORAN station which increased the available ecotonal regions that this species favored.

Table RTTB-2. Previous records of Red-tailed Tropicbirds on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	100	Eggs (Munter, 1915: 137).
1923	April 17-22	200	Fresh eggs to downy young (Wetmore, ms.).
1957	June 5	1,000	Nesting (Kenyon and Rice, 1958: 189).
1959	October 5-8	50	Nesting (Robbins, 1966: 53).
1960	March 28	100	Nesting (Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	Downy young to almost fledged young (Udvardy and Warner, 1964).
1962	February 2-4	25	(Robbins, 1966: 53).
	August 6-8	250	25 nests (Robbins, 1966: 53).
1963	February 3-7	25	1 nest (Robbins, 1966: 53).

Annual Cycle

At least a few Red-tailed Tropicbirds were recorded in every month. However, they were essentially absent from December through mid-February. Figure RTTB-1 shows the average number of tropicbirds counted flying over the island at 1400 hours during POBSP studies. Although most of these birds were non-breeders, this Figure best indicates the annual population cycle at Kure. The bimodal peak in summer may have been caused by inadequate data, by an influx of birds that had not bred previously, by individuals that lost nests earlier, or by a combination of these factors.

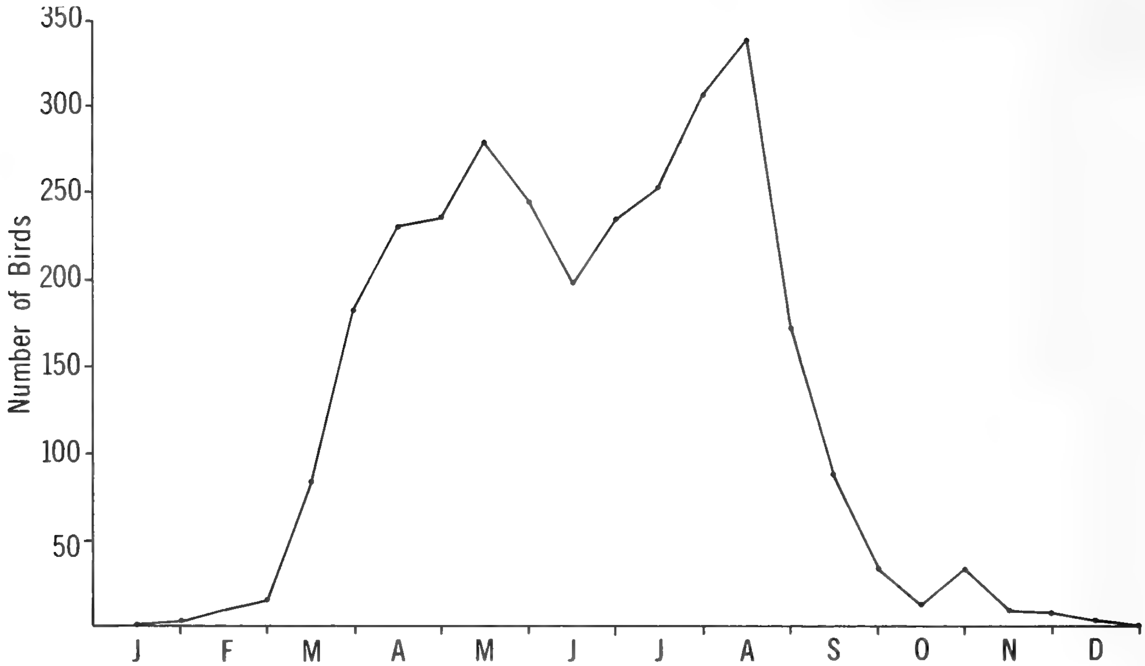

Figure RTTB-1. Annual population cycle of Red-tailed Tropicbirds flying over Green Island, Kure Atoll, 1964-69 (based on averages of counts made at 1400 hours).

Although Red-tailed Tropicbird nests were found in every month, the main breeding season extended from March through November. POBSP data indicated that breeding outside this period was rare. Due to the high rate of nest loss and renesting (e.g., in 1964, 46 of 62 [74.3 percent] of first breeding attempts in a study plot failed, and 54.3 percent of these pairs renested), it was difficult to reconstruct accurately a breeding cycle for this species; thus the 1967 and 1968 cycles, and to a lesser degree the 1966 cycle, were less accurately known than the 1964 and 1965 ones which were observed from initiation. Figure RTTB-2 shows the estimated number of nests present during the 1964 to 1966 cycles.

The available data (Table RTTB-3) indicate that there was some yearly variation in the timing of peak egg laying, perhaps as much as two weeks. Figure RTTB-3 shows the number of eggs laid each semimonthly period for four years in a study area at the southwest end of the runway. Peak egg laying occurred earlier in 1964 than in 1965 and extended later in 1966 than in 1965.

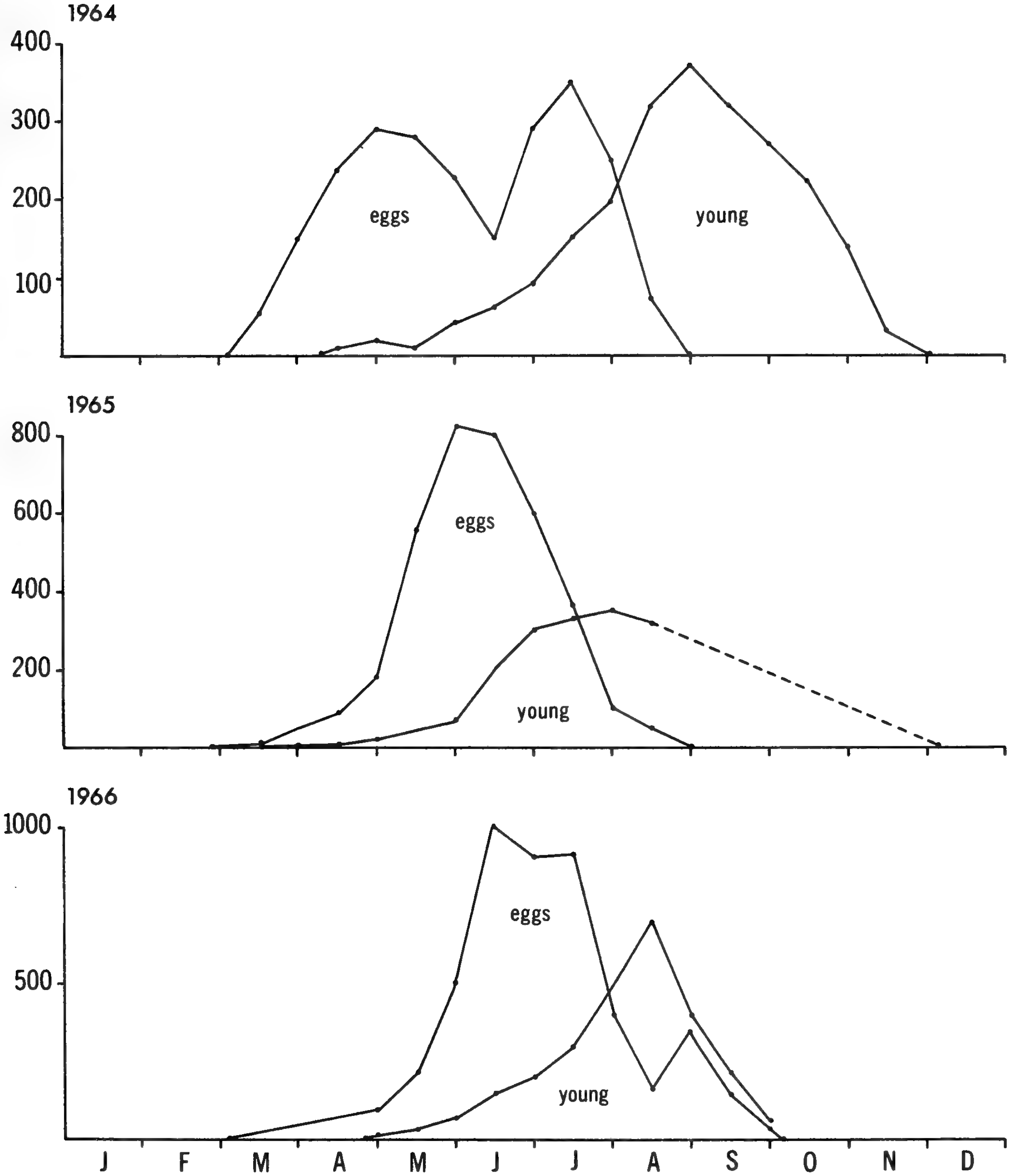

Figure RTTB-2. Breeding cycles of Red-tailed Tropicbirds on Green Island, Kure Atoll, 1964-66.

Table RTTB-3. Major periods in the Red-tailed Tropicbird breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	Early March-at least mid-July	Late February-at least early August	At least early March-at least mid-August	At least early March-at least early June	At least late March-at least mid-July	At least mid-March-at least early June
Peak Egg Laying	First two weeks of April; a secondary one in June	May-mid-June	May-June	May to at least mid-June	Late May and June	Probably May
Hatching	Mid-April-at least late August	Early April-at least mid-August	At least late April-at least early September	At least early May-?	At least early May-at least through August	At least mid-May-?
Peak Hatching	Late May-early June and early August	June	Late June-July	?	Late May and late June	?
Fledging	Early August-late November	Mid-July-early December	At least early August-?	Mid-June-?	Late July-November	?

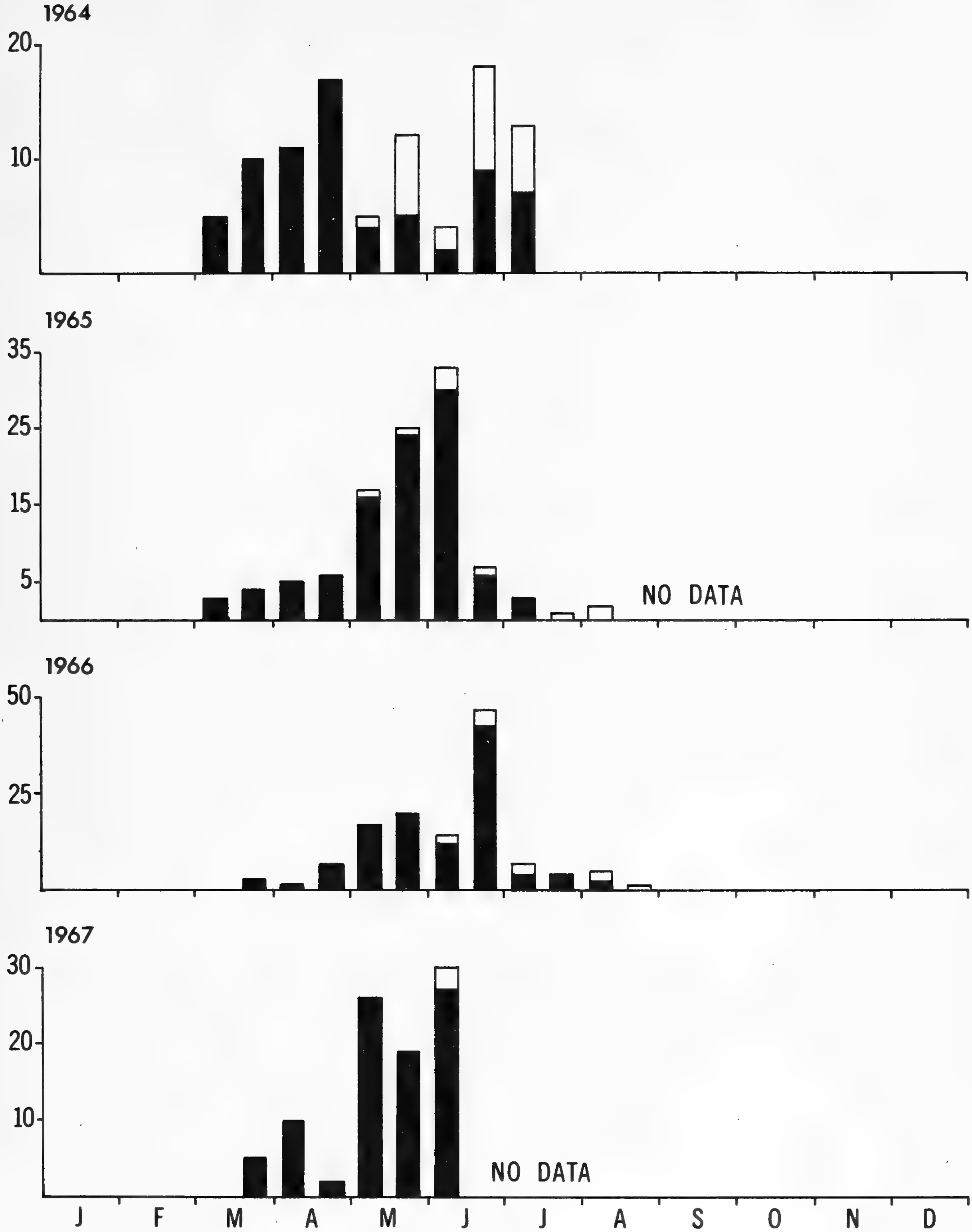

Figure RTTB-3. Number of Red-tailed Tropicbird nests in which first egg was laid each semi-monthly period in study area at west end of runway on Green Island, Kure Atoll, 1964-67.

Normally the first eggs of the new cycle were laid in late February or early March (earliest records: 20 February 1965 and 5 March 1964). Some eggs, usually from renestings, were laid as late as August. Combined data for the study area showed a peak of egg laying in May and June.

By early April some of the eggs began hatching, 40 to 46 days ($\bar{x}$=42.4, n=110) after oviposition. The last eggs hatched in early September. The period of peak hatching varied yearly from late May to early August. Combined data from the study area showed a peak from mid-June to early August.

Four POBSP records fall outside the limits outlined above: (1) an egg found on 2 November 1964, (2) a nestling of unknown age reported in early March 1964, (3) a nestling which fledged in early April 1965, indicating that the egg was laid in late November and hatched by mid-January, and (4) a nestling less than 10 days old found on 17 January 1966, indicating the egg was laid in late November.

Young tropicbirds began to fly 78 to 105 days ($\bar{x}$=85.4, n=38) after hatching. Thus fledging began in mid-June and continued through November. After fledging the young tropicbirds flew out to sea.

The earliest record the POBSP has of a young tropicbird returning to Kure is three years; it was banded as a chick in October 1963 and found breeding in September 1966. If Red-tailed Tropicbirds are similar to other seabirds, however, young return to the island at least one year prior to first breeding. Also, tropicbirds with heavy speckling on the dorsum, indicating that they were subadults, were seen in November 1964. Unpublished POBSP data indicate that this species attains adult plumage about two years after hatching. Thus Red-tailed Tropicbirds probably first return to the atoll when less than two years old.

Nesting Success

Table RTTB-4 summarizes Red-tailed Tropicbird productivity at Kure Atoll.

Detailed succsss data were collected in a study area of *ca.* 0.58 hectares at the southwest end of the runway from 1964 through 1966. The results of the first two years are being reported by Fleet (1972) and are briefly summarized in Table RTTB-5. In 1966, 119 pairs bred in the study area. Of these, 30 (25.2 percent) fledged young on the first attempt and 2 (1.7 percent) on the second. Fourteen pairs (11.8 percent) renested after the first nest failed. Polynesian rats were the major cause of nest loss in all years.

Table RTTB-4. Productivity of Red-tailed Tropicbirds on Green Island, Kure Atoll, 1964-68.

Breeding Season	Maximum Nest Estimate[1]	Maximum Egg Estimate	Maximum Nestling Estimate	Estimated Number of Young Fledged
1964	700	350	500	450
1965	1,000	825	335	350
1966	1,150	1,000	500	320
1967	1,305	1,230	200[2]	?
1968	940	750	400	300

[1] Maximum estimate for any semi-monthly period.

[2] Minimum figure.

Table RTTB-5. Results of Red-tailed Tropicbird breeding in a study area on Green Island, Kure Atoll, 1964-65*.

	1964	1965
First nesting:		
Number of pairs	62	97
Number of eggs lost	21	34
Percent of eggs hatched	66.1	64.9
Number of young lost	25	43
Percent of young lost	61.0	69.4
Number of young fledged	16	19
Percent of survival (yg fledged/eggs laid x 100)	25.8	19.6
Number of nest results unknown	-	1
Percent of nest results unknown	-	1.0
Renesting:		
Number of pairs renesting	25	12
Percent of pairs renesting (renesting/failures x 100)	54.3	15.6
Number of eggs lost	7	3
Percent of eggs hatched	76.0	41.7
Number of young lost	2	5
Percent of young lost	10.5	100
Number of young fledged	17	0
Percent of survival	68.0	0.0
Number of nest results unknown	-	4
Percent of nest results unknown	-	33.3

Table RTTB-5. (continued)

	1964	1965
Total young fledged	33	19
Total success (percent of total pairs)	53.2	19.6
Total success (percent of total nestings)	37.9	17.4

* Fleet (1972).

Ecology

Perhaps more than any other species, Red-tailed Tropicbirds were associated with the air space over the island. Their conspicuous aerial displays and vocalization were in marked contrast to their relatively secretive breeding habits. During their peak of diurnal activity at midday they were most abundant at the west end of the runway and over the southwest quarter of the island, less abundant but still common along the northwest beach, and scarce over the rest of the island. Presumably this abundance pattern reflected the distribution of nests.

Red-tailed Tropicbirds bred mainly under *Scaevola*, and secondarily under *Tournefortia*. Due to their awkwardness on the ground, their breeding sites were restricted to areas where they could crawl under the vegetation to find an open area from which to take off. Consequently, most nests were within 10 feet of the beach-*Scaevola* ecotone or around the edges of isolated patches of vegetation.

The adults dug a scrape in the soft sand, shaping it with their bodies. Here a single egg was laid. The distance between nests was determined by the availability of nest sites and the distance the incubating bird could reach with its bill. In 1968 detailed measurements were made of tropicbird nests in *Scaevola* clumps near the north point and along the lagoon beach. The former area measured *ca*. 864 inches by 720 inches and contained 12 nests, or 1 per 51,480 square inches. These nests averaged 66.4 inches from their nearest neighbors and 76.6 inches from the edge of the vegetation. Comparable figures for the latter area were 1 per 22,252 square inches, 62.1 inches, and 110.8 inches.

Non-breeding tropicbirds were found either flying over the island or roosting under *Scaevola* in potential breeding areas. Red-tailed Tropicbirds were frequently harassed by Great Frigatebirds until they disgorged their food.

Banding and Movements

Robbins banded 25 adult Red-tailed Tropicbirds and the POBSP banded an additional 1,973 adults. Recapture rates (Tables RTTB-6 and 7) of

Table RTTB-6. Recapture rates of adult Red-tailed Tropicbirds banded as non-breeders at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	3	100.0	33.3 (0.0)	33.3 (0.0)	33.3 (0.0)	33.3 (0.0)	33.3 (33.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1962	22	--	--	--	100.0	4.5 (0.0)	4.5 (0.0)	4.5 (0.0)	4.5 (4.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1963	120	--	--	--	--	100.0	25.8 (25.0)	5.0 (1.7)	3.3 (0.8)	2.5 (2.5)	0.0 (0.0)	0.0 (0.0)
1964	904	--	--	--	--	--	100.0	28.0 (21.6)	17.4 (14.6)	5.6 (0.9)	4.8 (0.0)	4.8 (4.8)
1965	127	--	--	--	--	--	--	100.0	22.1 (18.9)	5.5 (0.0)	5.5 (0.0)	5.5 (5.5)
1966	237	--	--	--	--	--	--	--	100.0	10.1 (3.0)	7.2 (0.0)	7.2 (7.2)
1967	11	--	--	--	--	--	--	--	--	100.0	0.0 (0.0)	0.0 (0.0)
1968	15	--	--	--	--	--	--	--	--	--	100.0	6.7 (6.7)
1969	94	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table RTTB-7. Recapture rates of adult Red-tailed Tropicbirds banded as breeders at Kure Atoll and recaptured there (expressed as percentages), 1964-69*.

Year Banded	n.	Year Recaptured 1964	1965	1966	1967	1968	1969
1964	126	100.0	34.1 (27.0)	23.0 (19.8)	4.0 (0.0)	4.0 (0.0)	4.0 (4.0)
1965	39	--	100.0	46.2 (43.6)	7.7 (0.0)	7.7 (0.0)	7.7 (7.7)
1966	81	--	--	100.0	23.5 (4.9)	18.5 (0.0)	18.5 (18.5)
1967	33	--	--	--	100.0	6.1 (0.0)	6.1 (6.1)
1968	7	--	--	--	--	100.0	0.0 (0.0)
1969	179	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

these birds were low due in part to the small number of tropicbirds handled in 1967 and 1968 (Table RTTB-8). An adult banded on 2 April 1964 flew aboard a ship at 4°40'N, 154°20'W on 30 November 1967.

Eight hundred and five nestling Red-tailed Tropicbirds were banded at Kure: 6 in 1959, 31 in 1963, 346 in 1964, 103 in 1965, 83 in 1966, 189 in 1967, 41 in 1968, and 6 in 1969. One of the 1963 cohorts, 5 of the 1964 cohorts, and 1 of the 1965 cohorts were recaptured in 1969. All but one were breeding. The 1963 banded Red-tailed Tropicbird also bred in 1966.

A nestling Red-tailed Tropicbird banded on 14 September 1964 was found breeding on Tern Island, French Frigate Shoals, on 8 June 1969. Another two of the 1964 cohorts were recovered at sea: 1 on 13 February 1967 at 31°39'N, 123°22'W and the other on 28 April 1970 at 38°30'N, 178°30'W. These recoveries and the one adult record indicate an easterly post-breeding dispersal of tropicbirds from the atoll.

Three Red-tailed Tropicbirds banded on other islands were recaptured at Kure: an adult banded at Midway Atoll on 29 July 1962 was found breeding on 21 September 1966, another adult banded at the same location on 25 June 1963 was found breeding on 20 July 1966, and an orange-streamered adult from Johnston Atoll was seen, but not caught on 8 August 1968.

Table RTTB-8. Number of Red-tailed Tropicbirds handled on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
Breeding adults	0	140	184	225	51	7	247
Non-breeding adults	120	922	213	293	15	15	116
Totals	120	1,062	397	518	66	22	363

WHITE-TAILED TROPICBIRD *Phaëthon lepturus*

Kepler observed a White-tailed Tropicbird as it flew over the southeast beach on 6 February 1965. This species breeds in the Main Hawaiian Islands (AOU, 1957) and has been reported breeding on Midway Atoll (Bailey, 1956).

BLUE-FACED BOOBY *Sula dactylatra*

Status

Common winter-summer breeder; *ca*. 54 pairs annually. Maximum yearly population *ca*. 160. Present all year. Breeds from late January through November.

Populations

Evidently the Blue-faced Booby population size decreased after the construction of the LORAN station as estimates made prior to 1959 (Table BFB-1) were larger than recent POBSP ones (Table BFB-2). To what degree it decreased is difficult to determine, however, since neither Munter nor Wetmore counted adults or nests. Kenyon and Rice's count of 80 nests in June 1957 was 10 higher than the maximum POBSP one. Undoubtedly the construction of the station and consequent disturbance of the breeding area played a significant role in this decrease.

Since POBSP studies began in 1963 the breeding population has fluctuated from a maximum of 140 in 1964 to a minimum of 78 in 1966. Enough data are available to examine some of the possible causes of these fluctuations, especially the 35 percent decrease from 1965 to 1966.

One hundred and forty-five adult Blue-faced Boobies which bred in 1964 and/or 1965 had been banded prior to 1964. In 1966, 28 of these birds (19.3 percent) disappeared from the population, presumably as a result of mortality. Twenty-five adults that bred in 1965 did not breed in 1966, 16 individuals reversed this pattern, and only 4 bird bred for the first time. Overall there was a net loss of 33 individual Blue-faced Boobies. Based on this, the major factor in this decline evidently was excessive adult mortality. By comparing individual breeding records for 1966 and 1967, however, a different picture develops.

In 1967, 35 individuals bred that did not breed in 1966, 4 birds reversed this pattern, 10 young birds bred for the first time, and only 1 bird was known to have disappeared; thus there was an overall gain of 40 Blue-faced Boobies, which increased the size of the breeding population almost to the 1965 level. Since the breeding population returned to the 1965 level so rapidly in 1967 (from 39 pairs to 56 pairs), due mainly to individuals breeding that had bred prior to 1966, this suggests that other factors besides adult mortality caused the decrease in 1966.

One striking feature of the 1966 breeding season was its lateness compared with other years (see Annual Cycle section). Perhaps in that year a segment of the population (those that bred in 1967 but not in 1966) reached the proper hormone level for breeding in January and February, but extrinsic environmental conditions at that time were

Table BFB-1. Previous records of Blue-faced Boobies on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	200	Nesting near center of island (Munter, 1915: 137).
1923	April 17-22	_ca_. 400	Common in open space at northern end of island; nesting; some had 2 eggs, others young 2 weeks old (Wetmore, ms.).
1957	June 5	170	80 nesting pairs; few nests contained 2 eggs; majority had newly hatched to nearly fledged young. Few birds in immature plumage (Kenyon and Rice, 1958: 189).
1959	October 3-8	85	Adults (Robbins, 1966: 53).
1960	March 28	110	55 nesting pairs (Robbins, 1966: 53).
1961	January 19-21	80	No nesting; adult count (Robbins, 1966: 53).
	September 12-14	numerous	Young from downy nestlings to almost fledged young (Udvardy and Warner, 1964: 2).
1962	February 2-4	80	3 nesting pairs (Robbins, 1966: 53).
	August 6-8	100	22 nesting pairs (Robbins, 1966: 53).
1963	February 3-7	56	3 nesting pairs (Robbins, 1966: 53).

unfavorable; consequently those birds did not lay eggs. When conditions again became favorable these birds had entered a refractory period and were unable to produce the necessary reproductive hormones; thus fewer birds than normal bred.

Apparently this decline in 1966 was caused in part by high adult mortality, and possibly in part by the internal physiology of the birds combined with as yet undetermined extrinsic environmental conditions.

Since almost all Blue-faced Boobies were banded, many of them as nestlings, population studies of this species were more detailed than those of any other species on the island. It is, therefore, worthwhile to summarize the preliminary findings here.

Table BFB-2. POBSP semi-monthly estimates of Blue-faced Boobies on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	141	132	-	80	-	120
16-31	-	140	125	*	-	-	120
February							
1-15	-	*	140	90	110	-	120
16-28	*	165	140	-	-	-	125
March							
1-15	-	150	150	-	-	-	120
16-31	-	150	140	-	140	120	130
April							
1-15	-	145	124	-	-	-	130
16-30	-	145	127	125	-	-	130
May							
1-15	100	145	129	116	129	-	130
16-31	-	145	125	112	135	114	135
June							
1-15	-	145	132	129	118	108	145
16-30	-	145	130	125	131	112	*
July							
1-15	-	150	130	125	-	119	-
16-31	-	150	138	125	-	130	-
August							
1-15	-	150	140	125	-	112	-
16-31	-	150	-	125	-	104	-
September							
1-15	-	150	-	125	-	110	-
16-30	*	150	-	125	-	116	-
October							
1-15	*	168	-	-	-	*	-
16-31	*	160	-	-	-	*	-
November							
1-15	275	156	-	-	-	*	-
16-30	225	168	60	-	-	*	-
December							
1-15	190	173	50	-	-	*	-
16-31	141	117	-	80	-	*	-

* Birds present, number unknown.

All available data indicated that all population growth in this species resulted from the recruitment of Blue-faced Boobies raised on Green Island. For the first two years of life these individuals wandered extensively and only occasionally roosted at Kure. By their third year, however, those Blue-faced Boobies that would eventually breed on the island roosted there regularly and began to pair off. Some even bred at this age, but the majority did not begin to breed until the fourth year. Limited data suggested that no individuals bred for the first time after their fifth year of life.

On the average, 13.1 percent of the adults breeding one year disappeared the next, presumably as a result of mortality. Balancing this loss was an average annual recruitment rate of 14.1 percent, 10.7 percent of which were banded as nestlings.

Every year an attempt was made to capture all breeding Blue-faced Boobies to determine the structure of the population. Tables BFB-3 and 4 summarize these data. It is evident that the Kure population was a healthy one with younger birds gradually replacing older adults which presumably died. In 1968, 25 percent of the breeding population was composed of known-age individuals.

From 1967 through 1969 the size of the breeding population remained fairly stable although its structure changed. By comparing breeding records of individual Blue-faced Boobies we can determine the actual changes in these populations each year. From 1967 to 1968 there was a decrease of 2 which resulted from the following: 21 individuals present in 1967 bred in 1968 (17 for the first time), 2 birds reappeared, 14 adults that bred in 1967 were unaccounted for, and 11 bred in 1967 but not in 1968 although they were still present. Another 84 birds bred in both years. Comparable statistics for 1969 were: 17 present in 1968 bred in 1969 (9 for the first time), 12 adults that bred in 1968 were unaccounted for, and 9 that bred in 1968 were still present but not breeding; there was, therefore, a loss of 4 individuals. Another 86 birds bred in both years.

Using the preceding data it is possible to predict the size of the 1970 breeding Blue-faced Booby population. In 1969 there were 103 breeding Blue-faced Boobies. An estimated thirteen of these birds will die before the 1970 breeding season and about 10 will be alive but not breed--a loss of 23 adults. To balance these anticipated losses there were, in 1969, 15 adult Blue-faced Boobies banded as nestlings that had not bred and 12 adults that had bred previously but not in 1969; thus in 1970, if all these birds breed, the breeding population could be 107. Based on 1968 and 1969 data, however, only 9 of the younger birds will breed, so the estimated population will be 101, or a slight decrease from 1969.

The main reason for the recent slight yearly decreases was the low survival rate of the 1965 cohort (see Nesting Success). Also, relatively

Table BFB-3. Structure of the breeding Blue-faced Booby population on Green Island, Kure Atoll, 1964-69.

Banded as adults in:		Number nesting in: 1964	1965	1966	1967	1968	1969
	1959	7	5	2	3	2	2
	1960	3	3	1	1	1	0
	1961	52	42	24	34	25	22
	1962	48	36	22	28	25	22
	1963	19	14	11	20	20	19
	1964	0	3	2	4	4	4
	1965	-	-	1	1	1	0
	1966	-	-	0	2	2	1
	1967	-	-	-	0	0	1
Banded as young in:							
(Nestl)	1959	1	1	1	1	1	1
(Imm)	1962	1*	1	4	10*	7*	8*
(Imm)	1963	0	0	0	3	9	7
(Nestl)	1964	-	0	0	2	10	14
(Nestl)	1965	-	-	0	0	0	2
Not recorded:		11	6	10	3	1	0
Totals		142	111	78	112	108	103

Table BFB-4. Structure of the breeding Blue-faced Booby population on Green Island, Kure Atoll, 1964-69 (expressed as percentages).

Banded as adults in:		Percent of the total population: 1964	1965	1966	1967	1968	1969
	1959	4.9	4.5	2.6	2.7	1.9	1.9
	1960	2.1	2.7	1.3	0.9	0.9	0.0
	1961	36.7	37.8	30.7	30.4	23.1	21.3
	1962	33.8	32.4	28.2	25.0	23.1	21.3
	1963	13.4	12.6	14.1	17.9	18.5	18.4
	1964	0.0	2.7	2.6	3.6	3.7	3.9
	1965	-	0	1.3	0.9	0.9	0.0
	1966	-	-	0	1.8	1.9	1.0
	1967	-	-	-	0.0	0.0	1.0
Banded as young in:							
(Nestl)	1959	0.7	0.9	1.3	0.9	0.9	1.0
(Imm)	1962	0.7*	0.9	5.1	8.9*	6.5*	7.8*
(Imm)	1963	0	0	0	2.7	8.3	6.8
(Nestl)	1964	-	0	0	1.8	9.3	13.6
(Nestl)	1965	-	-	0	0.0	0.0	1.9
Not recorded:		7.7	5.4	12.8	2.7	0.9	0.0

* 1 banded as subadult

few Blue-faced Boobies were raised in 1966, and apparently large numbers of them did not survive to maturity. The next few years the size of the breeding Blue-faced Booby population should either remain stable or decrease slightly. High survival rates of the 1967 to 1969 future cohorts will be necessary to increase the size of this population.

Besides the decrease in the size of the breeding population there was a decrease in the total number of Kure-based Blue-faced Boobies using the island (Table BFB-5). Excluding the subadults, many of which were probably from other islands, the island population decreased from 145 in 1967, to 140 in 1968, and to 133 in 1969.

Subadult Blue-faced Boobies formed an insignificant portion of the total population. Estimates included 4 from April to October 1966, 7 in May and June 1967, 3 in June 1968, 10 in July 1968, and 2 in February, 1 in April, 9 in May, and 16 in June 1969. There was an apparent increase of subadults in 1968 and 1969 when many, probably from other islands, were found roosting on the beaches.

Most subadults were individuals that had been raised at Kure in the previous two breeding seasons. They roosted for one or two days in the breeding area and then disappeared. Occasionally a Blue-faced Booby banded on another island was found roosting on the beach but only thrice, on 5 and 12 June 1968 and 21 April 1969, was a bird banded on another island found roosting on the central plain.

On the night of 16 July 1968, 6 Blue-faced Boobies were found roosting at the north point. This was the first time that any group which could be considered a club was found during POBSP studies. Smaller groups, composed mainly of subadults banded on other islands, were seen on 18, 24, and 25 July 1968. Since Green Island, in contrast to other islands, seldom had such roosting groups, its subadult population size was smaller than that generally found on other islands.

Table BFB-5. Number of Blue-faced Boobies handled each year on Green Island, Kure Atoll, 1964-69.

	1964	1965	1966*	1967	1968	1969
Breeding adults	131	105	68	108	107	103
Non-breeding adults	29	31	21	37	33	30
Subadults	6	0	3	5	7	20
Interisland	0	0	1	2	8	1
Totals	166	136	93	152	155	154

* No attempt made to catch all birds.

Annual Cycle

Blue-faced Boobies were permanent residents on Green Island. POBSP data indicated that they were more common during the breeding season than in the fall and early winter. After most young had fledged few adults roosted during the day in the central plain, but they returned to roost there at night. Whether any adults left the atoll for extended periods was not determined.

Subadult Blue-faced Boobies were present irregularly from May to February. There were a few records for the other months. It appeared that they were most common during the summer.

The Blue-faced Booby usually bred from late January through November, with a peak of egg laying in February and March, a peak hatching period in late March and April, and a peak fledging period in late July and August. Breeding in some years, however, deviated from this general cycle. For example, in 1966 egg laying did not begin until late March, and in 1965 and 1966 there were no apparent peaks of egg laying. Table BFB-6 compares yearly breeding cycles, and Figure BFB-1 shows the number of nests present each semi-monthly period.

The first eggs of each breeding season were laid on: 5 January 1964, 20 January 1965, ca. 16 March 1966, ca. 15 February 1967, ca. 29 January 1968, and ca. 21 January 1969; and the last eggs on: 29 June 1964, 13 July 1965, 5 June 1966, 1 July 1967, and 17 June 1968. Two POBSP records fall outside the above limits. On 20 October 1963 an egg was laid which disappeared by early December. On 12 November 1963 a young booby ca. three weeks old was found; presumably the egg had been laid on ca. 10 September and hatched ca. 22 October. This chick was not reported again.

Peak periods of egg laying varied considerably from year to year; Figure BFB-2 shows data for the north antenna field. When the data for all years were combined there was a major peak in February and March and lesser ones in April and late May (Fig. BFB-3). Much of the egg laying in May and June was the result of renesting.

On Kure, Blue-faced Boobies laid clutches of 1 or 2 eggs (Table BFB-7), with an average clutch size of 1.88. In 1966 the average differed significantly from most other years due to the lateness of the breeding cycle or to an inadequate food supply. Renesting pairs had an average clutch of 1.67 egg (n=24). From 2 to 12 days ($\bar{x}$=5.3, n=99) elapsed between the laying of the first and second eggs. Incubation began with the laying of the first egg.

Eggs hatched after an incubation period of about six weeks (Table BFB-8). The first eggs took on the average of one day longer to hatch than second eggs in the clutch. From 2 to 9 days ($\bar{x}$=4.7, n=50) elapsed between the hatching of two eggs in the same clutch.

Table BFB-6. Major periods in the Blue-faced Booby breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	ca. 5 January-29 June	20 January-early August	At least early March-5 June	Early February-at least early July	ca. 29 January-17 June	ca. 21 January-at least late May
Peak Egg Laying	February-mid March	None. Most eggs laid February and late March	None. Most eggs laid late March, late April, late May	Mid-March-mid-April	1-15 February, 15-31 March (late May-early June)	Late January, February and April
Hatching	21 February-late July	15 March-at least 15 July	27 April-18 July	ca. 28 March-at least 20 June	ca. 11 March-ca. 27 July	2 March-at least late June
Peak Hatching	Mid-March-mid-April	May and early July	May and early July	April and May	Mid-March-mid-April (July)	Last two weeks May
Fledging	Late July-late November	Mid-July-at least mid-November	Late August-mid-November	Late July*-late October	17 July-3rd week November	Early July*-at least late October

* Interpolated

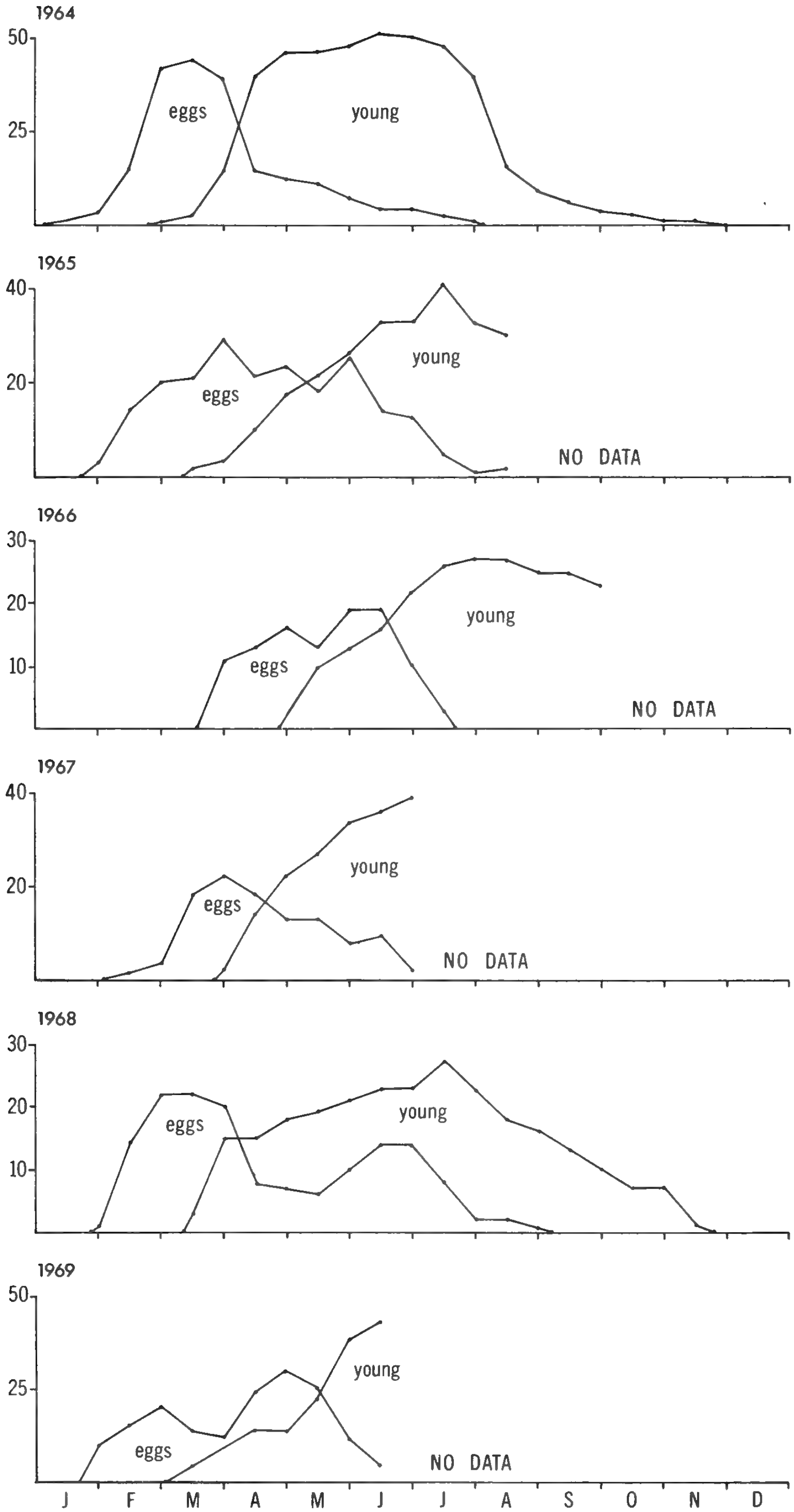

Figure BFB-1. Breeding cycles of Blue-faced Boobies on Green Island, Kure Atoll, 1964-69.

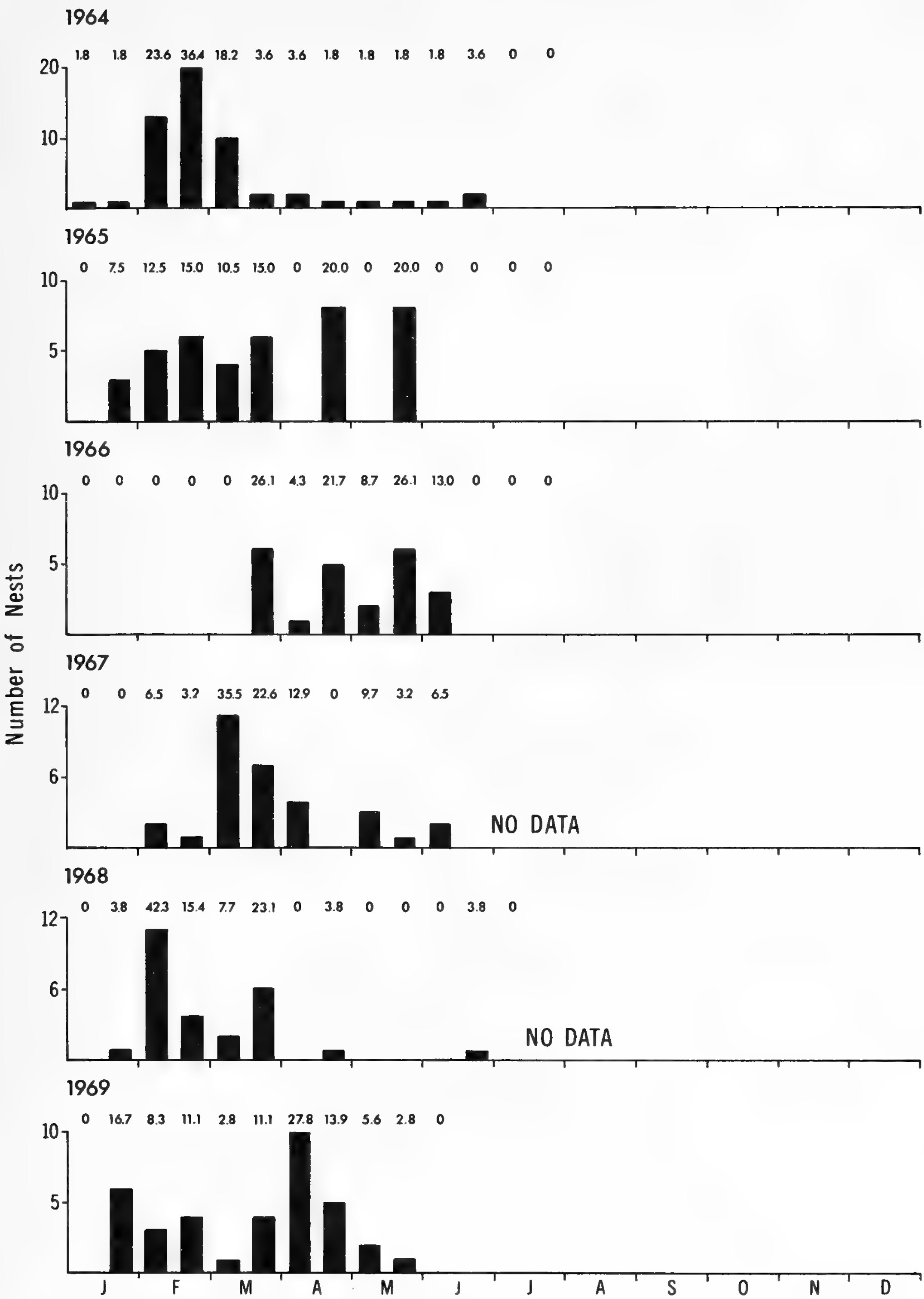

Figure BFB-2. Number of Blue-faced Booby nests in which first egg was laid each semi-monthly period in north antenna field, Green Island, Kure Atoll, 1964-69 (figures above bars indicate the percentage of total nestings that year).

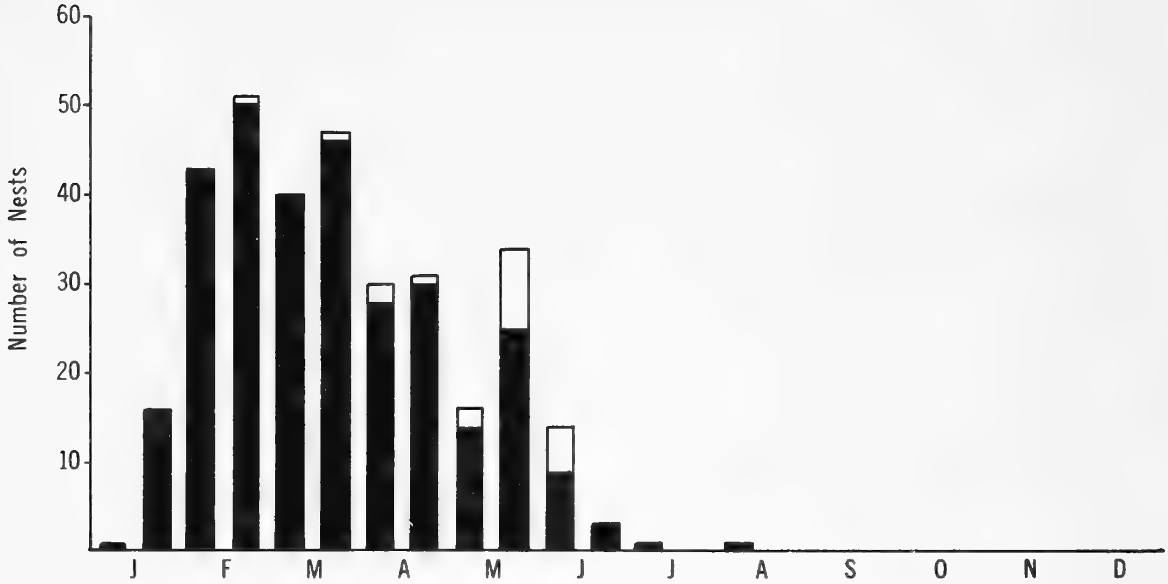

Figure BFB-3. Number of Blue-faced Booby nests in which first eggs were laid each semi-monthly period on Green Island, Kure Atoll, 1964-69 (combined data; white bars indicate re-nesting).

Table BFB-7. Clutch size of Blue-faced Boobies on Green Island, Kure Atoll, 1964-69.

Year	1-Egg	2-Egg	3-Egg	$\bar{x}$	n
1964	4	53	0	1.93	57
1965	5	34	0	1.88	39
1966	6	8	0	1.57	14
1967	2	3	0	1.60	5
1968	3	20	0	1.86	23
1969	4	49	1	1.94	54
Totals	24	167	1	1.88	192

Table BFB-8. Incubation periods for first and second eggs of Blue-faced Boobies on Green Island, Kure Atoll, 1964-69.

Year	First Egg Range	$\bar{x}$	n	Second Egg Range	$\bar{x}$	n
1964	40-48 days	43.9	37	40-45 days	42.5	24
1965	40-47 days	43.5	22	41-47 days	42.9	20
1966	43-46 days	43.9	7	41-44 days	42.5	4
1968	42-44 days	43.0	4	40-43 days	41.7	3
1969	42-45 days	43.6	27	41-45 days	42.9	22
$\bar{x}$	40-48 days	43.6	97	40-47 days	42.7	73

The first eggs hatched on 21 February 1964, 15 March 1965, 27 April 1966, ca. 28 March 1967, 11 March 1968, and 2 March 1969, and the last eggs hatched on 31 July 1964, 15 July 1965, 16 July 1966, at least 20 June 1967, and 24 July 1968. Peak hatching periods occurred 6 weeks after the egg laying peaks. Combined data (Fig. BFB-4) show a peak in late March and April.

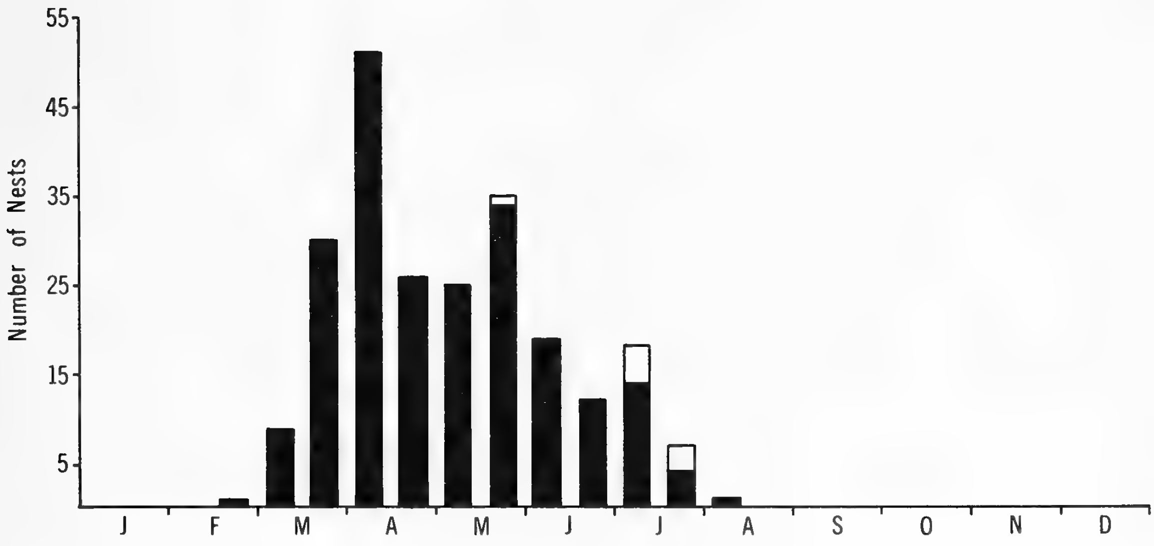

Figure BFB-4. Number of Blue-faced Booby nests in which first eggs hatched each semi-monthly period on Green Island, Kure Atoll, 1964-69 (combined data; white bars indicate re-nesting).

In 44 of 102 two-egg clutches (43.1 percent) laid from 1964 through 1966 both eggs hatched but only one young, usually the first to hatch, fledged. In 34 of the clutches (33.3 percent) one egg hatched and in the remaining 24 clutches no eggs hatched. Where both eggs hatched and the first chick was the one to survive, the second chick lived from 1 to 15 days ($\bar{x}$=3.7, n=38) after hatching.

The guard stage in this species was 29 to 84 days ($\bar{x}$=56.9, n=65). Young boobies began flying 109 to 151 days ($\bar{x}$=123, n=44) after hatching; hence fledging began in early July and continued through November with a peak in late July and August. These young returned to the nest site one to two months after fledging and then left the atoll; therefore, by mid-February none of the preceding breeding season's young remained on the island. Usually by early May a few of these birds again roosted on the island for short periods.

Nesting Success

Table BFB-9 summarizes Blue-faced Booby productivity from 1964 through 1969. In 1965 14.6 percent of the young were produced by renesting pairs. Comparable figures for other years were 5.9 percent in 1964, 0 percent in 1966, and 22.5 percent in 1968. Five young in 1965 and one in 1966 were produced from second eggs that were given to pairs that lost eggs or young. In all cases the donor pair's first egg hatched.

Sufficient data were collected from 1964 through 1966 to determine the success of the two clutch sizes (Table BFB-10) and the relative contribution of first and second egg to productivity (Table BFB-11). These data showed that two-egg clutches were more successful than one-egg clutches and that second eggs contributed significantly to overall productivity, suggesting that two-egg clutches have adaptive significance at Kure. Kepler (1969) discusses this adaptation in detail.

Detailed nesting success data were gathered in the north antenna field colony during 1964 and 1965, and to a lesser extent from 1966 through 1968 (Table BFB-12). It is obvious from this table that in all phases of reproduction, Blue-faced Boobies were successful breeders, especially considering the fact that although they may lay two eggs, a pair can only raise one young.

Rates of survival to sexual maturity of young Blue-faced Boobies (three years of age) were also high (Table BFB-13).

Ecology

Blue-faced Boobies bred in two distinct colonies, one in the north and one in the south antenna fields (Fig. BFB-5). The majority, 81.5 percent in 1964, 72.8 percent in 1965, 64.0 percent in 1966, 67.9 percent in 1967, 64.9 percent in 1968, and 64.8 percent in 1969, occurred

Table BFB-9. Productivity of Blue-faced Boobies on Green Island, Kure Atoll, 1964-69.

Year	Number of Nests	Number of Nests Fledging Young	% of Nests Fledging Young	Number of Young Banded
1964	70	50	71.5	50
1965	60	41[1]	68.3	38
1966	39	27[2]	69.2	27
1967	56	39	69.6	35
1968	54	31[3]	57.4	31
1969	51[4]	44[5]	86.4	21

[1] Produced by 6 re-nesters and 5 foster chicks. [2] 1 foster chick.
[3] 7 produced by re-nesters. [4] 4 not included in total.
[5] Number remaining on 20 June, including 6 foster chicks.

Table BFB-10. Success of first nesting attempts for two clutch sizes of the Blue-faced Booby on Green Island, Kure Atoll, 1964-66.

Year		1-Egg Clutch	2-Egg Clutch
1964	Success	2 (50.0%)	32 (65.3%)
	Failure	2 (50.0%)	17 (34.7%)
1965	Success	0 (0.0%)	25 (61.0%)
	Failure	6 (100.0%)	16 (39.0%)
1966	Success	5 (41.6%)	11 (84.6%)
	Failure	7 (58.4%)	2 (15.4%)
Totals	Success	7 (31.8%)	68 (66.0%)
	Failure	15 (68.2%)	35 (34.0%)

Table BFB-11. Contribution of first and second eggs to Blue-faced Booby productivity on Green Island, Kure Atoll, 1964-66.

Year	Number of Young Produced 1st Egg	2nd Egg
1964	29 (85.3%)	5 (14.7%)
1965	17 (68.0%)	8 (32.0%)
1966	14 (100.0%)	0 (0.0%)
Totals	60 (82.3%)	13 (17.7%)

Table BFB-12. Productivity of Blue-faced Boobies in the north antenna field based on first nesting attempts, Kure Atoll, 1964-69.

Year	Number of Nests	Number of Eggs Laid	Number of Eggs Hatched	Number of Young Fledged	% of Eggs Hatched	% of Young Fledged From: Eggs	Hatching	Nests
1964	57	110	67	36	60.9	32.7	53.7	63.0
1965	40	74	35	19	47.3	25.7	54.3	47.5
1966	25	38	22	16	57.6	42.1	72.7	64.0
1967	38	63	31	28	49.2	44.4	90.3	73.7
1968	35	59	20	12	33.9	20.3	60.0	34.3
1969	34	66	45	23*	68.1	34.8	51.1	69.7

* Number remaining on 20 June.

Table BFB-13. Survival rates of various Blue-faced Booby cohorts hatched on Green Island, Kure Atoll (expressed as percentages), 1959-69*.

		Year Recaptured										
Cohort	n.	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	16	100.0	6.3 (0.0)	6.3 (0.0)	6.3 (0.0)	6.3 (0.0)	6.3 (6.3)	6.3 (6.3)	6.3 (6.3)	6.3 (6.3)	6.3 (6.3)	6.3 (6.3)
1962	32	--	--	--	100.0	56.3 (37.5)	40.6 (31.3)	34.4 (18.8)	34.4 (21.9)	31.3 (28.1)	31.3 (28.1)	25.0 (25.0)
1963	43	--	--	--	--	100.0	39.6 (14.0)	35.0 (7.0)	30.2 (9.3)	27.9 (25.3)	23.2 (23.2)	21.0 (21.0)
1964	50	--	--	--	--	--	100.0	44.0 (2.0)	42.0 (6.0)	42.0 (38.0)	38.0 (38.0)	38.0 (38.0)
1965	38	--	--	--	--	--	--	100.0	18.4 (10.5)	18.4 (10.5)	15.8 (13.1)	15.8 (15.8)
1966	27	--	--	--	--	--	--	--	100.0	40.7 (18.5)	33.4 (22.2)	29.6 (29.6)

* All these birds were known to have fledged. First figures represent the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

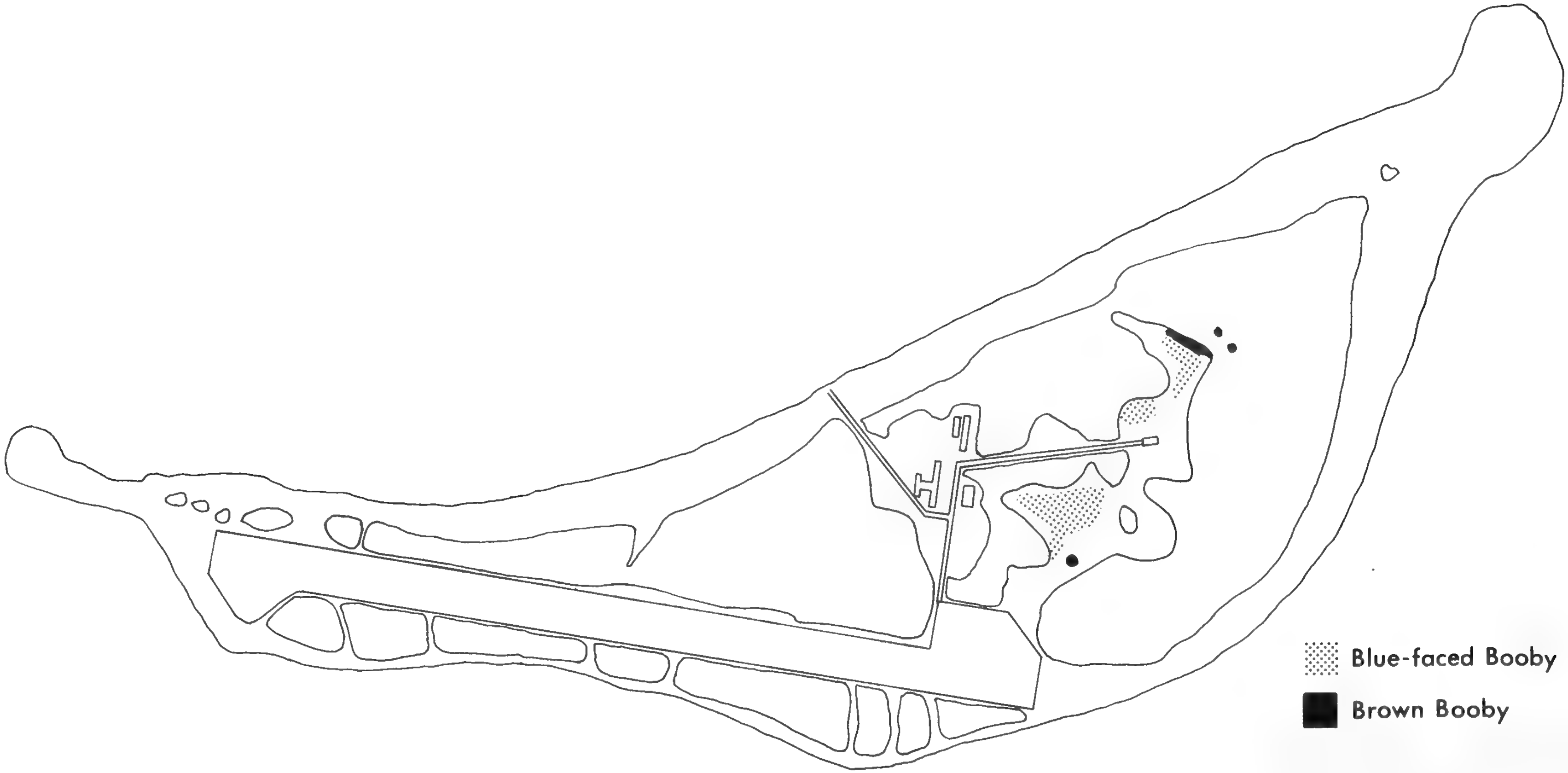

Figure BFB_-5. Distribution of breeding Blue-faced and Brown Boobies on Green Island, Kure Atoll.

in the former area. In 1964 one pair bred in the open area just south of the barracks, where there used to be a few nests prior to the construction of the Coast Guard station (Robbins, personal communication).

Nests were either clustered or solitary with the average distance from the closest neighbor 23 feet in 1964 and 25 feet in 1965 (Kepler, 1969). The range was from 5.5 feet to 89 feet. The size of the pair's territory was ca. 240 square yards, but only 60 square yards were actually utilized (Kepler, op. cit.).

Unlike Brown Boobies, Blue-faced Boobies bred in the open area of the central plain rather than along its edges. For the most part the breeding areas of these congeners did not overlap, although they sometimes bred as close as five feet to each other.

The nest was a simple scrape on the ground made by the male with its tail. The eggs were laid in a slight depression in the center of the scrape. Young Blue-faces eventually wandered from the scrape and soon Tribulus grew over the area. In 1967 a female, breeding for the first time, laid her egg on top of Tribulus.

The spreading of Verbesina in the central plain has changed the distribution of nests since 1964, especially in the south antenna field. In 1968 only an area of ca. 100 x 25 yards that had no Verbesina remained in this area. Most pairs bred there, but a few bred among the plants where there was enough open area. Previously nests had been widely distributed in this field.

The area just north of the transmitter building was also overgrown with Verbesina and only two pairs bred there in 1968 and 1969, although several pairs had bred there previously. As yet the plants have not invaded the major breeding area in the north antenna field.

Unmated birds and pairs that were not breeding generally roosted among the breeders. In 1968, however, many non-breeders roosted in the same general area of the north antenna field, with no breeders among them. There were breeders near the periphery of this group. Even these birds maintained territories.

Subadult Blue-faced Boobies, mainly Kure-raised birds, also occasionally roosted among the breeders, generally near their natal site. They also roosted on the beaches, generally at the north point.

Banding and Movements

Two hundred and twenty-two adult Blue-faced Boobies were banded at Kure Atoll. Table BFB-14 briefly summarizes the recapture of these birds at the atoll. Details of banding and recapture will be published separately.

Table BFB-14. Recapture rates of adult Blue-faced Boobies banded at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	25	100.0	36.0 (0.0)	36.0 (12.0)	32.0 (24.0)	32.0 (28.0)	32.0 (24.0)	24.0 (20.0)	16.0 (16.0)	12.0 (12.0)	8.0 (8.0)	8.0 (8.0)
1960	10	--	100.0	50.0 (10.0)	50.0 (40.0)	40.0 (40.0)	30.0 (30.0)	30.0 (30.0)	20.0 (10.0)	10.0 (10.0)	10.0 (10.0)	10.0 (10.0)
1961	75	--	--	100.0	88.0 (61.3)	85.3 (81.3)	78.7 (77.3)	65.3 (62.7)	53.3 (42.7)	53.3 (53.3)	44.0 (44.0)	36.0 (36.0)
1962	59	--	--	--	100.0	94.9 (91.5)	93.2 (91.5)	76.3 (72.9)	52.5 (37.3)	52.5 (52.5)	45.8 (45.8)	37.3 (37.3)
1963	35	--	--	--	--	100.0	85.7 (77.1)	74.3 (62.9)	60.0 (48.2)	60.0 (57.1)	57.1 (57.1)	54.3 (54.3)
1964	9	--	--	--	--	--	100.0	77.8 (55.6)	66.7 (55.6)	44.4 (44.4)	44.4 (44.4)	44.4 (44.4)
1965	1	--	--	--	--	--	--	100.0	100.0 (100.0)	100.0 (100.0)	100.0 (100.0)	0.0 (0.0)
1966	2	--	--	--	--	--	--	--	100.0	100.0 (100.0)	100.0 (100.0)	50.0 (50.0)
1967	1	--	--	--	--	--	--	--	--	100.0	100.0 (100.0)	100.0 (100.0)
1969	3	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Five of these adult Blue-faced Boobies were captured on other islands: 4 on Eastern Island, Midway Atoll and 1 on Laysan. Three of the birds found at Midway were breeding at the time of recapture. None had bred at Kure, nor did they return to Kure.

Robbins banded one subadult Blue-faced Booby in August 1962 and the POBSP banded 14 (2 in 1967, 2 in 1968, and 10 in 1969). Only the one banded in 1962 was recaptured. It bred at the atoll in 1964, 1967, 1968 and 1969.

Recaptures of nestling Blue-faced Boobies reaching sexual maturity have been summarized previously. In addition, 35 nestlings were banded in 1967, 31 in 1968, and 21 in 1969. Four of the 1967 cohorts were recaptured at Kure in 1968 and four in 1969, including one captured the previous year. In 1969 6 of the 1968 cohorts were captured.

Young Blue-faced Boobies raised at Kure traveled more extensively than the adults. Eight were found on other islands: 1 on Eastern Island, Midway Atoll, 1 on Southeast Island, Pearl and Hermes Reef, 3 on Lisianski, 1 at French Frigate Shoals, and 2 on Sand Island, Johnston Atoll. Two of these birds, one from Pearl and Hermes and one from Lisianski, returned to Kure. The Blue-face traveling to Midway was especially interesting. It was banded on 6 August 1962, recaptured at Kure on 26 October 1964 and 5 December 1965, and found breeding at Midway on 22 August 1966. This is one of the few records of a Blue-faced Booby hatched on one island breeding on another island.

Relatively little movement of Blue-faced Boobies from other islands to Kure Atoll was recorded: 1 from Eastern Island, Midway Atoll, 3 from Pearl and Hermes Reef, 5 from Lisianski, and 4 from French Frigate Shoals. This is not surprising since the atoll generally lacked permanent aggregations of non-breeders in which most interisland birds roost on other islands in the Northwest Hawaiian chain. All but two of these birds were banded as nestlings.

BROWN BOOBY — *Sula leucogaster*

Status

Common spring-summer breeder; *ca.* 40 pairs annually. Maximum yearly population *ca.* 100. Present all year but most numerous during breeding season. Breeds mainly from April through October.

Populations

Available data (Tables BB-1 and 2) indicated that Brown Boobies were about as numerous during the 1960's as earlier in the century. Munter's estimate was larger than any POBSP estimate, but since he did not count the birds it is difficult to determine the validity of his

Table BB-1. Previous records of Brown Boobies on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	ca. 200	Eggs present (Munter, 1915: 137).
1923	April 17-22	100	Eggs present (Wetmore, ms.).
1957	June 5	70	27 nests counted; out of 13 examined, 2 had 1 egg, 5 had 2 eggs, 1 had 2 newly hatched chicks, and 5 had 1 chick, the largest of which were half-grown and covered with down. Few birds in immature plumage (Kenyon and Rice, 1958: 189-190).
1959	October 3-8	50	Nesting (Robbins, 1966: 53).
1960	March 28	20	Nesting (Robbins, 1966: 53).
1961	January 19-21	1	Not nesting (Robbins, 1966: 53).
	September 12-14	?	(Udvardy, 1961: 46).
1962	February 2-4	5	Not nesting (Robbins, 1966: 53).
	August 6-8	40	19 nests (Robbins, 1966: 53).
1963	February 3-7	25	2 nests (Robbins, 1966: 53).

estimate. The only other previous numerical data were Kenyon and Rice's count of 27 nests in early July 1957. POBSP counts at the same time of year were similar, indicating little change in a decade. Since this species bred mainly along the edges of the central plain, its breeding habitat was not greatly altered by the construction of the LORAN station.

During POBSP studies an attempt was made each year to handle all Brown Boobies at the atoll. These data (Table BB-3) indicated a total yearly population of ca. 100 individuals, with no more than 84 breeding in any one year. Although the size of the breeding population remained relatively stable at ca. 40 pairs during POBSP studies, its structure, determined from the recapture of previously banded birds, changed (Tables BB-4 and 5). Like the Blue-faced Booby, the Brown Booby population maintained its stability through an influx of young birds and a decrease of older adults, a sign of a healthy population. From 1967 through 1969 there was an average annual adult mortality rate of 18.7 percent and an average recruitment rate of 17.7 percent.

Table BB-2. POBSP semi-monthly estimates of Brown Boobies on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	25	75	-	85	-	100
16-31	-	15	75	*	-	-	100
February							
1-15	-	*	75	2	8	-	100
16-28	*	25	75	-	-	-	60
March							
1-15	-	25	50	-	-	-	50
16-31	-	35	50	-	25	30	60
April							
1-15	-	35	46	-	-	-	75
16-30	-	63	45	30	-	-	75
May							
1-15	75	63	49	42	43	-	80
16-31	-	87	50	44	62	48	90
June							
1-15	-	87	70	65	66	49	100
16-30	-	87	80	75	74	46	*
July							
1-15	-	75	100	75	-	62	-
16-31	-	95	100	90	-	69	-
August							
1-15	-	95	90	100	-	64	-
16-31	-	95	-	72	-	62	-
September							
1-15	-	80	-	71	-	64	-
16-30	*	65	-	70	-	75	-
October							
1-15	*	60	-	-	-	*	-
16-31	*	75	-	-	-	*	-
November							
1-15	150	64	-	-	-	*	-
16-30	150	64	45	-	-	*	-
December							
1-15	88	55	40	-	-	*	-
16-31	65	50	-	85	-	*	-

* Birds present, number unknown.

Table BB-3. Number of Brown Boobies handled each year on Green Island, Kure Atoll, 1964-69.

	1964	1965	1966	1967	1968	1969*
Breeding adults	52	52	70	69	68	60
Non-breeding adults	25	35	13	11	20	11
Subadults	5	1	5	4	6	3
From other islands	0	0	3	2	0	0
Totals	82	88	91	86	94	74

* No attempt was made to catch all non-breeding birds.

Table BB-4. Structure of the breeding Brown Booby population on Green Island, Kure Atoll, 1966-69.

		Number breeding in:			
Banded as adults in:		1966	1967	1968	1969
	1959	2	2	1	1
	1962	12	11	7	6
	1963	15	15	13	10
	1964	23	20	16	14
	1965	7	8	10	6
	1966	7	5	5	4
	1967	-	4	4	3*
	1968	-	-	4	4
Banded as young in:					
	1957	1**	1**	1**	1**
	1959	1	0	1	0
	1962	1	1	1	3
	1963	1	2	4	3
	1964	0	0	3	4
	1965	0	0	2***	1
Not recorded:		12	7	8	14
Totals		82	76	80	74

* One from Pearl and Hermes Reef.
** From Midway Atoll.
*** One from Howland Island.

Table BB-5. Structure of the breeding Brown Booby population on Green Island, Kure Atoll, 1966-69 (expressed as percentages).

	Percent of total population breeding in: 1966	1967	1968	1969
Banded as adults in:				
1959	2.4	2.6	1.3	1.4
1962	14.6	14.5	8.8	8.1
1963	18.3	19.7	16.3	13.5
1964	28.0	26.3	20.0	18.9
1965	8.5	10.5	11.5	8.1
1966	8.5	6.6	6.3	5.4
1967	-	5.3	5.0	4.1*
1968	-	-	5.0	5.4
Banded as young in:				
1957	1.2**	1.3**	1.3**	1.4**
1959	1.2	0.0	1.3	0.0
1962	1.2	1.3	1.3	4.1
1963	1.2	2.6	5.0	4.1
1964	0.0	0.0	3.8	5.4
1965	0.0	0.0	2.5***	1.4
Not recorded:	14.6	9.2	10.0	18.9

* One from Pearl and Hermes Reef.
** From Midway Atoll.
*** One from Howland Island.

Unlike the case of the Blue-faced Booby, some of the Brown Booby population growth was the result of an influx of birds from other islands. Also, there was no indication that young Brown Boobies began roosting in the central plain one year prior to breeding for the first time. The number of non-breeding birds present one year does not indicate how many new breeders there will be the next year; it is thus impossible to predict the size of future breeding populations on the island.

Subadult Brown Boobies formed an insignificant proportion of the total Brown Booby population. During the year a few were present every month. For example, in May and June 1967, 1 to 3 were found each census night, while in 1968, from late May until early August, 1 to 3 were present on 3 of 10 census nights, and only 6 different individuals were captured during the period. Generally, these birds had been raised on Green Island in previous years.

Annual Cycle

Although Brown Boobies roosting in the central plain were easily enumerated, many individuals, especially during the non-breeding season, did not roost there. Therefore, counts included only a portion of the population and were less accurate than the Blue-faced Booby censuses. Consequently the Brown Booby annual population cycle was not accurately determined. However, POBSP data suggested the following cycle. Brown Boobies were present all year, with maximum populations during the breeding season. After breeding most adults left the central plain and roosted in Scaevola, on the reef, or on the beaches. At this time they were relatively inconspicuous. Some adults may actually have left the atoll. As breeding progressed, more and more birds roosted in the central plain.

Brown Boobies bred in all months, but the main breeding season was from April through October. Figure BB-1 shows the number of nests with eggs and the number with young for each semi-monthly period when POBSP personnel were present. Unlike Blue-faced Boobies, Brown Boobies showed little yearly variation in the breeding cycle (Fig. BB-2 and Table BB-6). Only in 1968, when breeding began in February and no egg laying peak occurred, was any significant variation noted.

Eggs were laid in all months except December, but most egg laying occurred from April through July. Earliest egg dates for each breeding season were 1 April 1964, late March 1965, 14 April 1966, ca. 19 March 1967, ca. 8 February 1968, and ca. 10 April 1969. Combined data show a peak period of egg laying in May and June (Fig. BB-3).

Brown Boobies laid a clutch of one to three eggs, but the usual clutch was two (Table BB-7). Three to nine days ($\bar{x}$=5.2; n=85) elapsed between the laying of the first and second eggs.

Since incubation began before the second egg was laid, hatching was asynchronous. On Kure the interval between hatching of eggs in the same clutch averaged 4.6 days (range 1-9 days, n=52), slightly less than the average interval between egg laying. Incubation periods for the first and second eggs laid did not differ significantly (Table BB-8). No third egg hatched.

In the study years the first egg hatched on: 18 May 1964, early May 1965, 25 May 1966, ca. 30 April 1967, 21 March 1968, and 20 May 1969. Some eggs hatched in January, October, and December, but no young fledged from the three nests observed. Combined data show that the peak period of hatching occurred in June and July (Fig. BB-4).

Although both eggs may hatch, only one of the young usually survived. In 1964, for example, in 18 of 23 (78.1 percent) two-egg clutches, both eggs hatched, but in only one case, where the eggs hatched one day apart, did both young fledge. Only one other nest produced two young: in 1965,

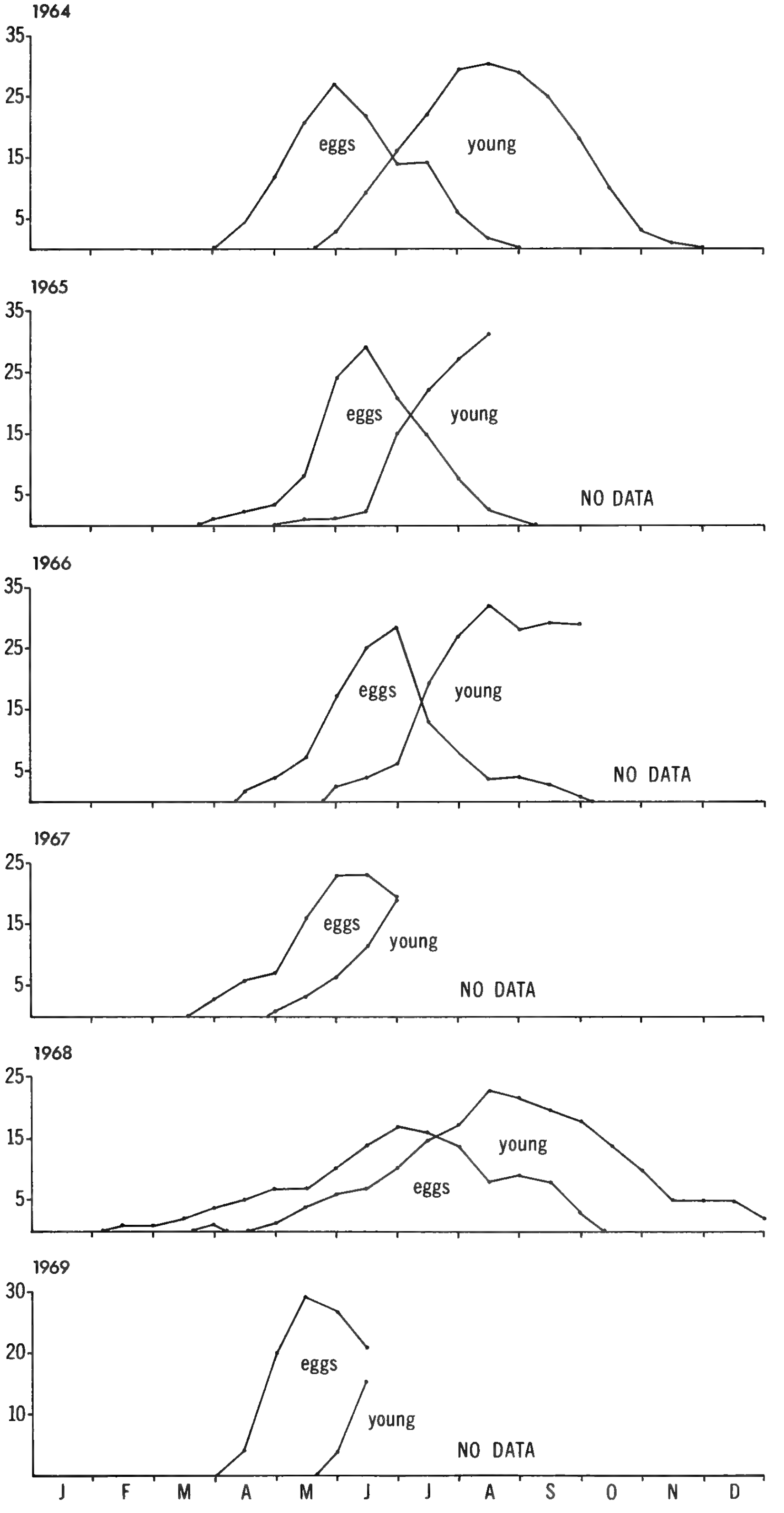

Figure BB-1. Breeding cycles of Brown Boobies on Green Island, Kure Atoll, 1964-69.

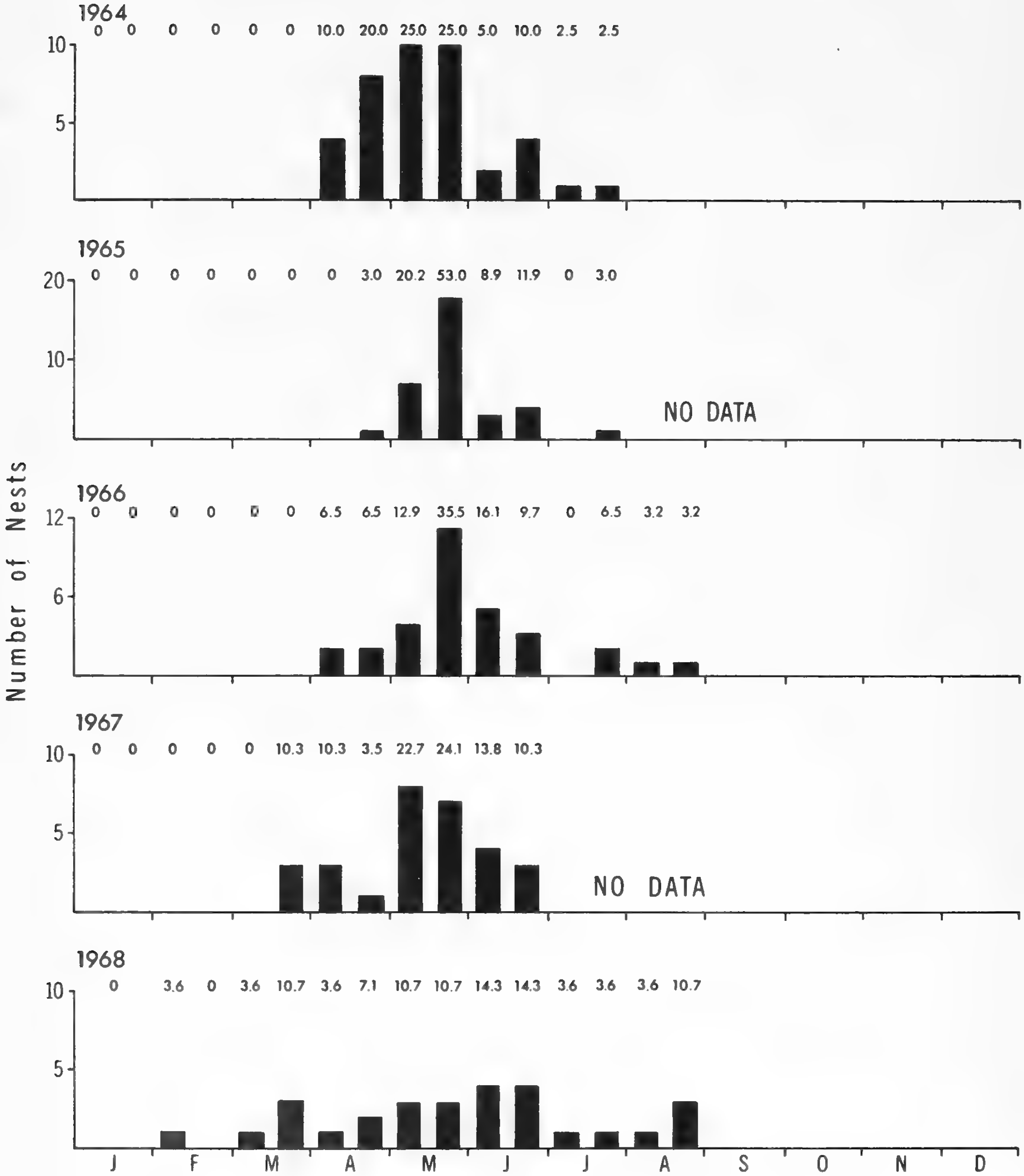

Figure BB-2. Number of Brown Booby nests in which first egg was laid each semi-monthly period in north antenna field, Green Island, Kure Atoll, 1964-68(figures above bars indicate the percentage of total nestings that year).

Table BB-6. Major periods in the Brown Booby breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	_ca_. 1 April-1 July	Late March-29 July	14 April-26 August	_ca_. 19 March-at least late June	_ca_. 8 February-28 August	Early April-at least early June
Peak Egg Laying	Mid-April-late May	May	Last two weeks May	May	None. Most eggs laid in May and June	Late April-at least mid-May
Hatching	18 May-late August	Early May-_ca_. 9 September	25 May-_ca_. 7 October	_ca_. 30 April-at least early August	_ca_. 21 March-9 October	Late May-?
Peak Hatching	June-July	Mid-June-mid-July	July	Mid-June-mid-July	None. Most eggs hatched mid-June-mid-August	?
Fledging	Late August-late November	6 August-early December	26 July-late December	Late July*-mid-November	19 July-10 January 1969	?

* Interpolated

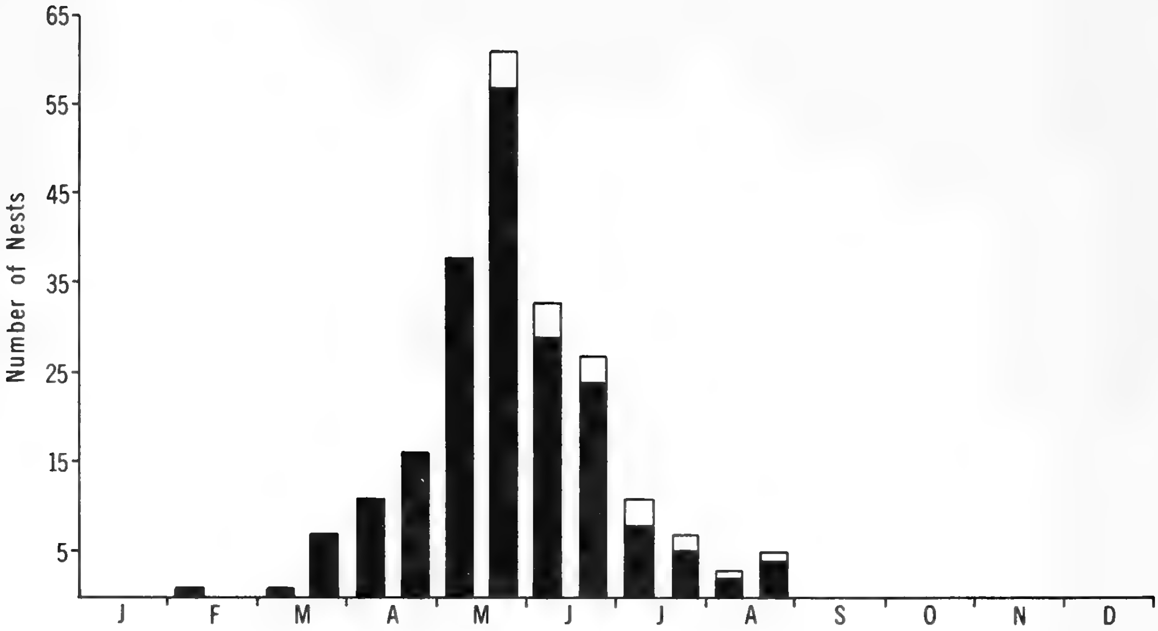

Figure BB-3. Number of Brown Booby nests in which first eggs were laid each semi-monthly period on Green Island, Kure Atoll, 1964-68 (combined data; white bars indicate re-nesting).

Table BB-7. Clutch size of Brown Boobies on Green Island, Kure Atoll, 1964-68.

Year	1 Egg	2 Eggs	3 Eggs	$\bar{x}$	n
1964	2	26	3	2.03	31
1966	4	22	3	1.97	29
1967	0	16	2	2.11	18
1968	1	14	0	1.93	15
Total	7 (7.5%)	78 (83.9%)	8 (8.6%)	2.01	93

Table BB-8. Incubation periods for first and second eggs of Brown Boobies on Green Island, Kure Atoll, 1964-68.

Year	First Egg Range	First Egg $\bar{x}$	First Egg n	Second Egg Range	Second Egg $\bar{x}$	Second Egg n
1964	40-46 days	42.3	23	40-44 days	42.2	22
1965	41-45 days	42.1	10	No data		0
1966	39-48 days	42.6	18	41-44 days	42.4	12
1967	40-45 days	42.3	3	41-42 days	41.5	2
1968	42-43 days	42.5	8	40-44 days	41.9	8
$\bar{x}$	39-48 days	42.4	62	40-44 days	42.2	44

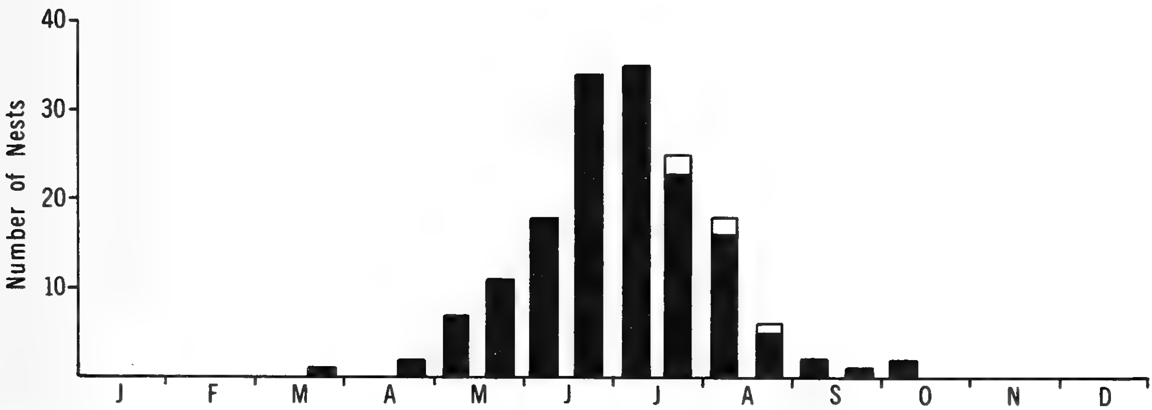

Figure BB-4. Number of Brown Booby nests in which first eggs hatched each semi-monthly period on Green Island, Kure Atoll, 1964-68 (combined data; white bars indicate re-nesting).

one egg hatched on 9 July and the other one on 12 July; both nestlings were still alive and healthy on 15 August. With these exceptions, the life span of the second chick on Kure ranged from one to seven days ($\bar{x}$=4.1; n=41).

Much of the egg laying in the latter part of the season was the result of re-nesting. Table BB-9 summarizes re-nesting data for 1964, 1966, and 1968.

Table BB-9. Re-nesting of Brown Boobies on Green Island, Kure Atoll.

	One Egg 1964	1966	1968	Total	Two Eggs 1964	1966	1968	Total
Number of nests lost	6	4	5	15	4	3	3	10
Number of re-nestings	3	2	2	7	0	1	3	4
% of re-nestings	50.0	50.0	40.0	46.7	0	33.3	100.0	40.0

	Three Eggs 1964	1966	1968	Total	Nestling 1964	1966	1968	Total
Number of nests lost	1	2	0	3	2	0	2	4
Number of re-nestings	0	2	0	2	0	0	2	2
% of re-nestings	0	100.0	0	66.7	0	0	100.0	50.0

	Combined 1964	1966	1968	Total
Number of nests lost	13	9	10	32
Number of re-nestings	3	5	7	15
% of re-nestings	23.1	55.6	70.0	46.9

Young Brown Boobies fledged 85 to 103 days ($\bar{x}$=94.7; n=30) after hatching. Thus, in five seasons of observation fledging began as early as late July and continued into December, with a peak usually occurring in September-October. Fledglings returned to their nest sites for one or two months after fledging, but all those that survived eventually left the atoll. POBSP data indicate that most Brown Boobies were absent from the atoll for their first two years of life and returned sometime during their third or fourth year. Some three-year-old birds bred.

Nesting Success

Tables BB-10 to 12 present Brown Booby productivity data for 1964 to 1968. The most detailed data were collected in 1964 and 1966 in the north antenna field when all nests were checked daily. As can be seen, Brown Boobies were relatively successful breeders and ca. 30 young were produced annually.

Enough data were collected in 1964 and 1966 to determine the relative contribution of first and second eggs to productivity (Table BB-13), the relative contribution of re-nesting pairs (Table BB-14), and the nesting success of the various clutch sizes (Table BB-15). These data indicate that two-egg clutches were adaptive on Kure as they produced more young than any other clutch size, and the second egg laid contributed significantly to overall productivity. Although the nesting success of Brown Boobies was high, survival to sexual maturity (three years), or at least the rate of return to the atoll, was low (Table BB-16). This may be related to the long distances young Brown Boobies traveled after fledging (see Banding and Movements). Their destinations were often inhabited areas where they were probably subjected to heavy human predation.

Ecology

Brown Boobies bred in small groups or, rarely, in individual pairs on the central plain and adjacent grassy areas. Most nests were found in the north antenna field (43 in 1964, 34 in 1965, 31 in 1966, and 29 in 1967, 1968 and 1969), rather than in the south antenna field (5 in 1964, 11 in 1965, 10 in 1966, 9 in 1967, 8 in 1968, and 9 in 1969). In the former area nests were placed along the edge of *Scaevola* at the western side of the field, resulting in a rather linear distribution extending ca. 100 yards in a northeast to southwest direction (Fig. BB-5). In the latter area nests were confined to an area within 50 feet of an isolated *Scaevola* clump at the southern end of the field. Occasional nests were present on *Tribulus*-covered dunes just north of the north antenna field. Only rarely was a Brown Booby nest nearer than 5 feet to a Blue-faced Booby nest.

The nests, generally substantial structures of *Scaevola* twigs and leaves with some *Solanum*, *Tribulus*, *Verbesina*, *Eragrostis*, and *Boerhavia*, were built on the ground. Some nests contained very little vegetation, with the eggs almost on the ground, while others were 3 inches deep. A sample of 10 nests had an average outer diameter of 12.7 inches, an average inner diameter of 7.1 inches, and an average depth of 1.4 inches. The central portion was depressed from the weight of the incubating bird. After the eggs hatched, most of the nest was destroyed by the movements of nestlings and adults. *Tribulus* and *Scaevola* surrounded many of the nests.

Table BB-10. Productivity of Brown Boobies in the north antenna field based on first nesting attempts, 1964-68*.

Year	Number of Nests	Number of Eggs Laid	Number of Eggs Hatched	Number of Young Fledged	% of Eggs Hatched	% of Young Fledged From: Eggs	Hatching	Nests
1964	37[1]	71	50	27[2]	70.4	38.0	54.0	73.0
1965	33[1]	56[3]	33[3]	24[2]	58.9	42.9	72.7	72.7
1966	31[1]	60	33	24	55.0	40.0	72.7	77.4
1967	18[4]	37[3]	24[3]	18[5]	64.9	48.6	75.0	100.0
1968	32	55[3]	31[3]	19	56.4	34.5	61.3	59.4

* 1969 data inadequate for inclusion in this table.
[1] One not included. [2] Two young fledged from same nest. [3] Minimum figure.
[4] Eleven not included. [5] Number remaining in early July.

Table BB-11. Productivity of Brown Boobies in the south antenna field, Green Island, Kure Atoll, 1964-68*.

Year	Number of Nests	Number of Nests Fledging Young on First Attempt	Number of Nests Fledging Young on Second Attempt	Total Number Produced	Percent Success
1964	5	5	0	5	100.0
1965	11	11	0	11	100.0
1966	10	8	0	8	80.0
1967	5[1]	4[2]	0	4	80.0
1968	8	7	0	7	87.5

* 1969 data inadequate for inclusion in this table.
[1] Four not included. [2] Number remaining in early July.

Table BB-12. Productivity of Brown Boobies on Green Island, Kure Atoll, 1964-68*.

Year	Number of Nests	Number of Nests Fledging Young	% of Nests Fledging Young	Number of Young Banded
1964	42[1]	31	74.5	29
1965	44[1]	34	77.3	23
1966	41	34	82.9	34
1967	23[2]	22[3]	95.5	17
1968	40	29	72.5	29

* 1969 data inadequate for inclusion in this table.

[1] One not included. [2] Fifteen not included. [3] Number remaining in early July.

Table BB-13. Contribution of first and second Brown Booby eggs to productivity, Green Island, Kure Atoll.

Year	1st egg	2nd egg
1964	21 (80.8%)	5 (19.2%)
1966	20 (86.9%)	3 (13.1%)
Totals	41 (83.7%)	8 (16.3%)

Table BB-14. Contribution of re-nesting Brown Boobies to productivity, Green Island, Kure Atoll.

Year	First attempt	Second attempt
1964	26 (96.3%)	1 (3.7%)
1966	23 (92.0%)	2 (8.0%)
Totals	49 (94.2%)	3 (5.8%)

Table BB-15. Success of first nesting attempts for various clutches of Brown Boobies on Green Island, Kure Atoll.

Year		1-Egg Clutch	2-Egg Clutch	3-Egg Clutch
1964	Success	1 (25.0%)	23 (82.1%)	1 (33.3%)
	Failure	3 (75.0%)	5 (17.9%)	2 (66.7%)
1966	Success	1 (33.3%)	20 (87.0%)	2 (50.0%)
	Failure	2 (66.7%)	3 (13.0%)	2 (50.0%)
Totals	Success	2 (28.6%)	43 (84.3%)	3 (42.9%)
	Failure	5 (71.4%)	8 (15.7%)	4 (57.1%)

Table BB-16. Recapture rates of various Brown Booby cohorts from Green Island, Kure Atoll (expressed as percentages), 1959-69*.

		Year Recaptured										
Cohort	n.	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	22	100.0	4.6 (0.0)	4.6 (0.0)	4.6 (0.0)	4.6 (0.0)	4.6 (0.0)	4.6 (0.0)	4.6 (4.6)	4.6 (4.6)	4.6 (4.6)	0.0 (0.0)
1962	18	--	--	--	100.0	33.3 (0.0)	33.3 (16.7)	27.8 (11.1)	22.2 (5.6)	22.2 (16.7)	16.7 (11.1)	16.7 (16.7)
1963	30	--	--	--	--	100.0	30.0 (0.0)	26.6 (0.0)	26.6 (20.0)	23.3 (10.0)	23.3 (20.0)	13.3 (13.3)
1964	29	--	--	--	--	--	100.0	27.6 (3.5)	27.6 (3.5)	27.6 (6.9)	27.6 (17.2)	13.8 (13.8)
1965	23	--	--	--	--	--	--	100.0	13.0 (13.0)	4.4 (4.4)	4.4 (4.4)	4.4 (4.4)
1966	34	--	--	--	--	--	--	--	100.0	8.8 (8.8)	0.0 (0.0)	0.0 (0.0)

* All these birds were known to have fledged. First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Non-incubating Brown Boobies roosted either on the ground next to the incubating birds or in the Scaevola near the nests. While guarding the younger nestlings, the adults roosted on the ground, but many of the older young roosted on Scaevola next to their parents. Some breeding adults roosted at night outside the central plain in such areas as the north tower, or in Scaevola along the northwest beach.

Non-breeding Brown Boobies generally roosted outside the central plain on the north tower, at the north point, in Scaevola along the northwest beach or, more rarely, in the north roost, along the southwest beach, or on coral blocks near the southeast beach. During the day Brown Boobies were commonly seen standing on the reef.

Banding and Movements

One hundred and forty-eight adult Brown Boobies were banded at Kure Atoll. Table BB-17 briefly summarizes the recapture of these birds. Details of this study will be published later. One adult female Brown Booby banded on 8 November 1964 was recaptured at Pearl and Hermes Reef on 18 March 1965 and 21 March 1967.

One subadult banded in 1962, one banded in 1966, and two in 1968 were not recaptured.

The recapture of nestling Brown Boobies reaching sexual maturity has been previously summarized. In addition, 17 nestlings of the 1967 cohort were banded and 29 of the 1968 cohort. Four of the 1967 cohort were captured in 1968 and 2 of the 1968 cohort were recaptured the next year.

Young Brown Boobies wander extensively. An immature banded on 4 October 1963 was captured at Wake Atoll on 19 June 1966 and later at Kure on 2 January 1967. Four other Brown Boobies banded as nestlings were recovered in the Pacific Basin (Table BB-18). These data suggest a southerly dispersal of young Brown Boobies after fledging.

Three Brown Boobies banded on other islands bred at Kure: a nestling banded on Eastern Island, Midway Atoll, in 1957 bred at Kure each year from 1966 to 1969; a breeding adult male banded on Southeast Island, Pearl and Hermes Reef, on 28 August 1967 also bred at Kure in 1969, and an adult female banded on Howland Island as an immature on 1 February 1965 was found roosting on Green Island on 15 June 1966 and 8 July 1967, and breeding in 1968. This is one of the few recorded movements of a bird from central equatorial Pacific islands to the Northwest Hawaiian Islands. Another three Brown Boobies (two banded as nestlings and one as an adult male) were recaptured at Kure, but not found breeding.

Table BB-17. Recapture rates of adult Brown Boobies banded at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	9	100.0	22.2 (0.0)	22.2 (0.0)	22.2 (11.1)	22.2 (0.0)	22.2 (22.2)	22.2 (11.1)	22.2 (22.2)	22.2 (22.2)	11.1 (11.1)	11.1 (11.1)
1962	22	--	--	--	100.0	72.7 (4.6)	72.7 (68.2)	63.6 (59.1)	50.0 (50.0)	40.9 (40.9)	31.8 (27.3)	27.3 (27.3)
1963	28	--	--	--	--	100.0	64.3 (50.0)	64.3 (46.4)	64.3 (64.3)	57.1 (57.1)	53.8 (42.9)	46.4 (46.4)
1964	42	--	--	--	--	--	100.0	73.8 (54.8)	61.9 (57.1)	54.8 (52.4)	42.9 (35.7)	38.1 (38.1)
1965	17	--	--	--	--	--	--	100.0	76.5 (41.2)	64.7 (47.1)	58.8 (52.9)	47.1 (47.1)
1966	12	--	--	--	--	--	--	--	100.0	66.7 (58.3)	58.3 (58.3)	41.7 (41.7)
1967	7	--	--	--	--	--	--	--	--	100.0	57.1 (57.1)	42.9 (42.9)
1968	9	--	--	--	--	--	--	--	--	--	100.0	22.2 (22.2)

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table BB-18. Brown Boobies banded as nestlings at Kure Atoll and recovered at various locations.

Date Banded	Where Found	When Found	Distance (nautical miles)	How Obtained
4 October 1963	Marshall Islands: Majuro Atoll	17 April 1964	1,388	Trapped
22 July 1966	Indonesia: Central Moluccas	21 March 1968	3,564	Found after storm
30 August 1966	Ellice Islands: Funafuti Atoll	3 March 1967	2,187	Found dead
17 July 1968	Ellice Islands: Funafuti Atoll	9 May 1970	2,187	Shot

RED-FOOTED BOOBY *Sula sula*

Status

Abundant winter-summer breeder; 175 to 430 pairs annually. Present all year with peak numbers from May through October. Breeding generally begins in March and continues through November.

Populations

Both Munter's and Wetmore's estimates (Table RFB-1) were larger than any POBSP estimate (Table RFB-2). At the time of their visits *Scaevola* covered considerably more area than it does today, consequently, there was more available breeding habitat for this species. Whether the number of Red-foots has decreased, however, is questionable, for today large areas of *Scaevola* are not utilized by breeding birds, suggesting that breeding Red-foots used no more area in 1915 and 1923 than they do today. Perhaps these observers were over-enthusiastic in their estimates, a real possibility since they made no counts.

Kenyon and Rice's estimate was based on a nest count during the peak of the breeding season and was on the same order of magnitude as recent POBSP estimates, again suggesting that Red-foots are as abundant today as earlier in this century.

POBSP estimates were based mainly on counts of roosting birds. This method was accurate only in a general way because it was difficult, if not impossible, to see from the radar reflector and north tower all Red-foots roosting in the *Scaevola*. A simple example will illustrate. On 18 May 1967, 106 Red-foots, including breeding birds, were counted at

Table RFB-1. Previous records of Red-footed Boobies on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	2,000	Eggs (Munter, 1915: 137).
1923	April 17-22	2,000	Few eggs; most pairs nest building or selecting nest sites (Wetmore, ms.).
1957	June 5	*ca*. 500	Estimates 240 nests based on count of 218 (Kenyon and Rice, 1958: 190).
1959	October 3-8	300	(Robbins, 1966: 53).
1960	March 28	600	Nesting (Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	Nesting (Udvardy and Warner, 1964: 2).
1962	February 2-4	75	(Robbins, 1966: 53).
	August 6-8	500	240 nesting pairs (Robbins, 1966: 53).
1963	February 3-7	240	(Robbins, 1966: 53).

sunset in the central roost. The next day at sunset, 95 individuals were seen in the north roost. At this time there were *ca*. 147 nests in the central roost and *ca*. 282 in the north roost, so the roost counts did not even equal the number of incubating or brooding adults.

Far more accurate, especially for comparison, than roost counts were the nest counts of 1965 through 1969, and the 1964 estimate. These were fairly consistent at *ca*. 200 pairs, but in 1967 there was at least a 147 percent increase from 1966 and a 74 percent increase from 1965, the previous maximum count. What caused this increase is unknown, but a few possibilities, such as an influx of birds from other islands or a large number of young Red-foots nesting for the first time, will be examined with the aid of banding and recapture data.

Breeding Red-foots were sampled three times, on 27 June, 2 July, and 4 July 1967, in as random a way as possible. One hundred and twenty-five individuals were handled. Since the maximum nest count was 429, these samples represented *ca*. 13.8 percent of the breeding population. Seventy-nine of the 125 (63.2 percent) Red-foots handled were already banded. Table RFB-3 summarizes the history of these birds. By using the derived percentages we can determine the number of each class in the

Table RFB-2. POBSP semi-monthly estimates of Red-footed Boobies on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	175	700	-	137	-	750
16-31	-	175	400	*	-	-	800
February							
1-15	-	400	400	225	380	-	600
16-28	*	375	600	-	-	-	700
March							
1-15	-	550	600	-	-	-	800
16-31	-	550	500	-	*	450	800
April							
1-15	-	550	350	-	-	-	800
16-30	-	550	350	400	-	-	800
May							
1-15	1,000	550	400	500	1,075	-	1,000
16-31	-	550	400	500	1,075	1,000	1,000
June							
1-15	-	550	550	400	1,075	1,000	1,000
16-30	-	550	550	700	1,075	1,000	*
July							
1-15	-	600	550	500	1,075	1,000	-
16-31	-	700	600	700	-	1,000	-
August							
1-15	-	700	550	750	-	1,000	-
16-31	-	700	-	700	-	1,000	-
September							
1-15	-	550	-	550	-	1,000	-
16-30	*	700	-	600	-	750	-
October							
1-15	*	700	-	-	-	*	-
16-31	*	700	-	-	-	500	-
November							
1-15	400	800	-	-	-	500	-
16-30	400	800	350	-	-	500	-
December							
1-15	400	800	300	-	-	500	-
16-31	350	646	-	137	-	*	-

* Birds present, number unknown.

Table RFB-3. Number and percentage of total number of previously banded Red-footed Boobies captured in samples of breeding birds on Green Island, Kure Atoll, 1967.

Year of Banding	Number Captured:* Adult	Subadult	Immature	Local
1962	1 (1.3%)	0	0	3^{+1B} (3.8% + 1.3%)
1963	10 (12.7%)	0	4 (5.1%)	0
1964	21^{+1A} (26.6%+1.3%)	1 (1.3%)	4 (5.1%)	0
1965	4 (5.1%)	0	0	0
1966	26 (32.9%)	3 (3.8%)	0	0

* Age at banding. A = Banded on Wake Atoll. B = Banded on Midway Atoll.

total population. For example, since there were 542 (0.63 x 858) banded Red-foots in the population and 1.3 percent of these were banded in August 1962, it then follows that 6 (542 x 0.013) individuals in this class were present. Table RFB-4 gives the calculated totals for each class.

Table RFB-4. Structure of breeding Red-footed Booby population on Green Island, Kure Atoll, 1967.

Unbanded Red-footed Boobies: 316

Banded Red-footed Boobies: 542 in the following age classes:

Year of Banding	Age when banded: Adults	Subadults	Immatures	Locals
1962	6	0	0	21^{+6B}
1963	69	0	28	0
1964	144^{+6A}	6	28	0
1965	28	0	0	0
1966	179	21	0	0
Totals	426^{+6A}	27	56	21^{+6B}

A = Banded on Wake Atoll. B = Banded on Midway Atoll.

With these data we can examine three possible reasons for the 1967 increase: (1) an influx of Red-foots from other islands; (2) large numbers of young birds breeding for the first time; and (3) many of the Red-foots banded as adults in 1966 breeding for the first time. Based on banding data these would result in the following increases, respectively: 6.7 percent, 24.7 percent, and 51.7 percent, by themselves not enough to account for the total increase. Even if all the unbanded individuals were added to each class, resulting in increases of 97 percent, 115.6 percent, and 142.6 percent, they do not account for the increase. It is also unlikely that all unbanded birds belonged to only one group. When considered together, however, they may provide a sufficient explanation. It is worth mentioning at this point that roost counts made in May and June 1967 were at the same level as those made during the same period in 1966. Perhaps there was actually no appreciable change in the population size, but rather that more Red-foots bred in 1967 because of favorable environmental conditions which at the moment are unknown. In this respect it should be noted that this increase occurred after the year when the smallest number of Red-foots recorded during POBSP studies bred, and that the population in 1968 was only slightly above the 1965 level.

The 31.3 percent increase from 1968 to 1969 followed a similar pattern, i.e., an increase after a decrease and a later breeding season. This correlation between size of the breeding population and the timing of the breeding cycle has been discussed previously. The breeding population was not sampled for banded birds in 1969 to determine other possible causes for the increase.

Unlike the other sulids on the island, subadult Red-footed Boobies formed a significant portion of the total Red-foot population. For example, in late May 1966 this group composed an estimated 20 percent of the population. These birds were present all year, but data were insufficient to determine accurately population fluctuations through an entire season. Available estimates include: 0 in late February 1964 and late March 1968, 3 in late March 1965, 1 in early January 1967, 100 in late May 1966, 200 in May and June 1967, 60 in May 1968, 100 in June 1968, and 150 to 200 in July 1968. These data show that subadult Red-foots occurred more commonly in summer than in winter.

Beginning in April 1966 an attempt was made each month that POBSP observers were on the island to catch as many subadult Red-foots as possible. It was soon discovered that the plumage of these birds varied considerably. Each individual captured was placed in one of three categories -- subadult brown, subadult white-brown, or subadult white-- based on its plumage. (Details of this study will be published later). Although the exact chronology is unknown, the available data based on 51 birds banded as nestlings indicate that it takes three years to acquire adult plumage and that subadult browns are one year old, subadult white-browns are two years old, and subadult whites are three

years old. This knowledge enables one to comment on the age structure of the subadult population. Table RFB-5 summarizes the age structure of the subadult population for those birds that were handled.

Table RFB-5. Age structure of subadult Red-footed Booby population on Green Island, Kure Atoll, in May-July 1967 and 1968 (expressed as percentages).

Age	1967	1968
One year	19.7%	50.9%
Two years	55.3%	37.0%
Three years	25.0%	12.1%
Number handled	76	108

The relative increase of one-year-old birds in 1968 probably resulted from the high productivity of the breeding population in 1967 compared with 1966.

Although population studies of young Red-foots are still in the embryonic stage, it may be worthwhile at least to summarize the available data. Tables RFB-6 to 8 list by year the number of subadults that were caught, how many were previously banded, and the history of these banded birds. These data show or suggest the following: (1) subadults were present from April to October; (2) Red-foots from other islands were present from May to October; (3) birds from the 1966 cohort were present in June, July 1967; and May, June, July 1968; (4) birds from the 1967 cohort were present in May, June, July 1968; (5) a relatively large percentage of the previously banded birds had been banded on other islands (60 percent in 1966, 40 percent in 1967, and 23.6 percent in 1968); (6) the 1966 Kure cohort was apparently more common in 1968 than in 1967. This last statement requires some explanation. In 1967, 15 percent (6 of 40) of the banded Red-foots handled had been banded as nestlings in 1966; in 1968, 41.2 percent of the 51 previously banded birds were in this group, suggesting that more had returned to the island since 1967. Without data from a complete year it is difficult to attach much significance to these observations.

Annual Cycle

Red-footed Boobies occurred throughout the year with peak populations present from May through October, the period of peak breeding activity. The smallest populations were recorded in January, February, and December. Whether or not all members of the breeding population were present every month was not determined.

Red-footed Boobies bred on a well-defined annual cycle which usually began in March and ended in November. Like their congeners, *Sula dactylatra*, Red-foots showed some yearly variation (Table RFB-9).

Table RFB-6. Summary of subadult Red-footed Boobies handled on Green Island, Kure Atoll, April-October 1966.

	April	May	June	July	August	September	October
Previously banded	0	14	13	7	5	3	2
Unbanded	8	29	41	31	21	9	1
Repeats	0	0	0	14	7	7	0
Totals	8	43	54	52	33	19	3

Distribution of returns:

	April	May	June	July	August	September	October
Banded on Kure as:							
Imm. 1963	0	0	1	1	0	0	0
Local 1964	0	0	2	0	0	0	0
Imm. 1964	0	6	3	3	0	1	1
Subadult 1965	0	1	1	0	0	0	0
Banded on:							
Midway Atoll	0	4	2	0	2	1	1
Laysan	0	0	0	0	1	1	0
French Frigate Shoals	0	0	1	0	0	0	0
Mokapu Point, Oahu	0	0	1	1	0	0	0
Sand Island, Johnston Atoll	0	3	0	2	2	0	0
Wake Atoll	0	0	2	0	0	0	0

For example, the peak period of egg laying was almost two months later in 1966 than in 1964. Figure RFB-1 shows the number of nests with eggs and the number with young for each semi-monthly period POBSP personnel were present.

Egg laying was known to begin as early as late January, but usually did not start until early March. The peak period of egg laying varied yearly from mid-March to early June. Generally there was only one peak, but in 1968 there were two, slightly over two months apart (Fig. RFB-2). Only one egg was laid per nest. Eggs were laid as late as late June.

Eggs hatched approximately six weeks after being laid. Therefore, hatching began as early as mid-March and continued until late August.

Table RFB-7. Summary of subadult Red-footed Boobies handled on Green Island, Kure Atoll, May-July 1967.

Class		Number handled: May	June	July	Total number handled	% of subadult population	Structure of returns	May	June	July
Brown	B*	1	5	1			Banded on Kure			
(1 year old)	U**	0	6	2	15	19.7	as: Nestl. 1966	0	4	1
							Imm. 1966	1	0	0
		1	11	3						
							Banded on:			
							Kauai	0	1	0
White-Brown	B*	2	11	9						
(2 year old)	U**	2	15	3	42	55.3	Banded on Kure			
							as: Nestl. 1966	0	1	0
		4	26	12			Imm. 1966	0	0	2
							Suba. 1966	1	5	3
							Banded on:			
							Midway	0	1	0
							Laysan	1	0	2
							Lisianski	0	1	0
							Wake	0	3	2
White	B*	0	7	4						
(3 year old)	U**	0	4	4	19	25.0	Banded on Kure			
							as: Imm. 1964	0	1	0
		0	11	8			Suba. 1966	0	2	3
				Total	76		Banded on:			
							Midway	0	3	1
							Lisianski	0	1	0

B* - Previously banded (returns).
U** - Unbanded.

Table RFB-8. Summary of subadult Red-footed Boobies handled on Green Island, Kure Atoll, May-July 1968.

Class		Number handled: May	June	July	Total number handled	% of subadult population	Structure of returns	May	June	July
Brown	B*	5	6	8			Banded on Kure			
(1 year old)	U**	8	2	26	55	50.9	as: Nestl. 1967	5	6	4
		13	8	34			Banded on:			
							Lisianski	0	0	3
							Sand-Johnston	0	0	1
White-Brown	B*	7	3	16						
(2 year old)	U**	3	5	6	40	37.0	Banded on Kure			
							as: Nestl. 1966	4	2	15
		10	8	22			Suba. 1967	2	0	0
							Banded on:			
							Lisianski	0	1	0
							French Frigate	0	0	1
							Wake Atoll	1	0	0
White	B*	3	0	3						
(3 year old)	U**	3	1	3	13	12.1	Banded on Kure			
							as: Nestl. 1966	0	0	1
		6	1	6						
							Banded on:			
				Total	108		Midway Atoll	2	0	0
							Pearl and Hermes	0	0	1
							Lisianski	1	0	0
							French Frigate	0	0	1

B* - Previously banded (returns).
U** - Unbanded.

Table RFB-9. Major periods in the Red-footed Booby breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	Late February-mid-May	Late January; mid-March-at least end of June	Late March-early June	Early March-June	Early March-*ca.* 21 June	Late January-at least early May
Peak Egg Laying	Late March-mid-April	3rd week May	Last week May	Late April	Late March, first 2 weeks June	Mid-March-mid-April
Hatching	Early May-late June	Mid-May-at least mid-August	Early May-late August	Mid-April-?	Mid-April-*ca.* 2 August	Mid-March-at least late June
Peak Hatching	May	1st week July	First 2 weeks July	Early June	First 2 weeks May; last 2 weeks July	Last 2 weeks May
Fledging	*ca.* July-December	?-December	August-?	Mid-July-?	Late July-?	?

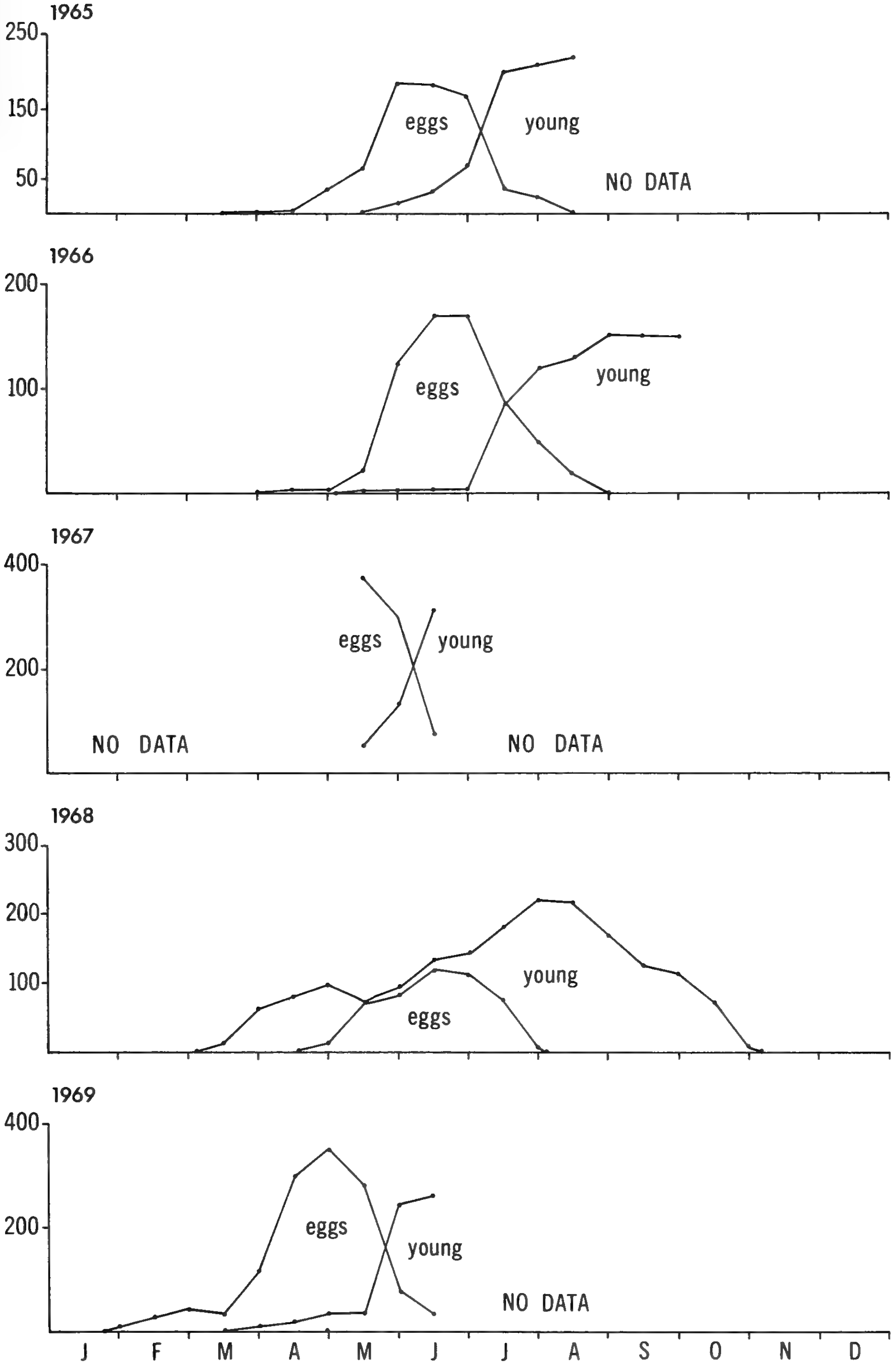

Figure RFB-1. Breeding cycles of Red-footed Boobies on Green Island, Kure Atoll, 1965-69.

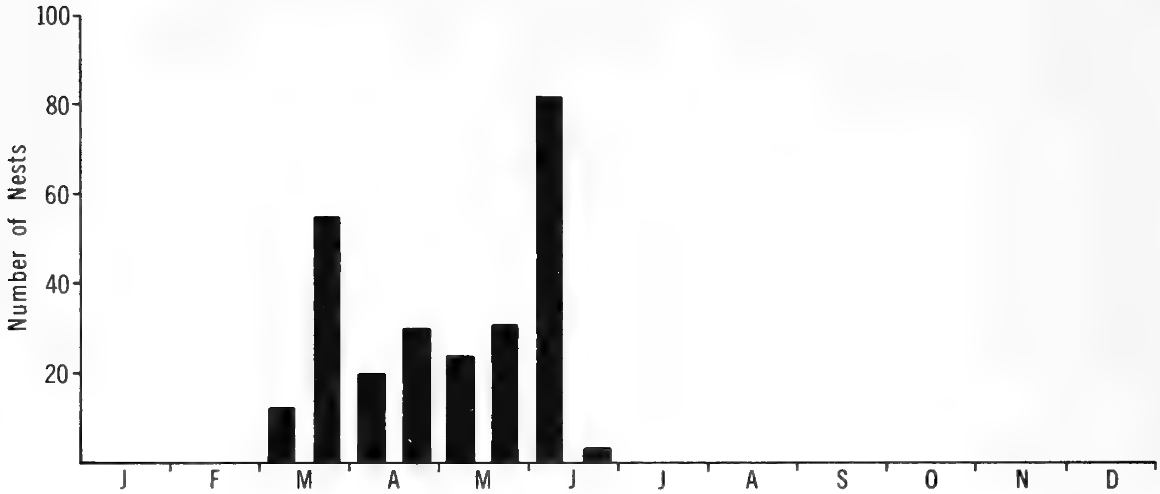

Figure RFB-2. Number of Red-footed Booby nests in which first egg was laid each semi-monthly period on Green Island, Kure Atoll, 1968.

Hatching peaks varied from May to July. Not enough numerical data were available to determine the peak periods of egg laying and hatching for all years combined.

Young Red-foots began to fledge in mid-July. Fledging continued into December. Approximately 13 weeks elapsed between hatching and fledging. These birds returned to roost in the nesting areas for one or two months after fledging. Most, if not all, eventually left the island. In 1969 all of the 1968 cohort had left by mid-February. However, by at least May some were again roosting on the island.

Nesting Success

Table RFB-10 summarizes Red-footed Booby productivity for 1964 through 1969.

The only detailed success data were collected in 1968 in the central roost for three different groups of nests (Table RFB-11). These figures compare favorably with data for other sulids at Kure.

Table RFB-10. Productivity of Red-footed Boobies on Green Island, Kure Atoll, 1964-69.

Year	Maximum Nest Count or Estimate	Maximum Egg Count or Estimate	Maximum Nestling Count or Estimate	Estimate of Young Fledged	Approximate Percent Fledged**
1964	200	-	200	200	-
1965	241*	189*	200*	200	82.9
1966	174	170	150	135	77.6
1967	429*	395*	324*	300	66.9
1968	297*	121	256*	225	75.7
1969	390	350	250***	-	-

* Count.
** Percent of young fledged from highest nest count or estimate.
*** Number remaining on 20 June.

Table RFB-11. Nesting success of three groups of Red-footed Booby nests in the central roost, 29 May-10 August 1968.

Group I: Nests that contained eggs on 29 May

n = 27
70.4% hatched
70.4% young remaining on 10 August from eggs laid
100.0% young remaining on 10 August from eggs hatched

Group II: Nests that contained young on 29 May

n = 43
100.0% hatched
34.9% fledged by 10 August
58.1% young remaining on 10 August
93.0% probable fledging success

Group III: Nests started after 29 May

n = 26
65.4% hatched
61.5% young remaining on 10 August from eggs laid
94.1% young remaining on 10 August from eggs hatched

All Groups:

Nests with eggs

67.9% hatched
66.0% of all eggs laid will probably fledge young
97.2% of all hatched eggs will probably fledge young

Table RFB-11. (continued)

All nests

82.3% hatched
78.1% of all eggs laid will probably fledge young
94.9% of all hatched eggs will probably fledge young

Ecology

Red-footed Boobies bred mainly in Scaevola, and also in the northernmost Tournefortia along the northeast beach. Here they built bulky nests of Solanum vines and some Ipomoea and Scaevola. Occasional sprigs of green Boerhavia were added during the incubation period. Red-foots gathered these materials in open areas, mainly the central plain, by pulling vigorously at the live plants until the vine broke. Almost all, if not all, of the birds used only one or two areas from which to gather vegetation during one breeding season. After a while little green vegetation was left in these areas. As far as could be determined, only adult males gathered nesting materials. A few subadults were also seen pulling at the vines.

Nests were built by placing the vines on a supporting platform of branches, which were sometimes on the same bush and at other times formed by interlocking branches of different bushes. Generally, nests were near the top of Scaevola bushes, but some were well below the level of surrounding vegetation. It appeared that some Red-foots broke off Scaevola leaves and twigs surrounding the nests. The height of nests from the ground ranged from two to at least seven feet, depending on the height of the vegetation. In 1967, 10 nests averaged 44.4 inches from the ground. These same nests had an average outer diameter of 13.2 inches, an average inner diameter of 5.8 inches, and an average depth of 3.1 inches.

Usually Red-foots bred in small groups among other Red-foots or among Great Frigatebirds. The distance between nests was determined by the availability of nest sites and the range of the incubating bird's bill, nests being no closer than a bird could reach. For the most part, nests were found in the center of vegetated areas rather than along the edges.

The main breeding areas were in the north and central roosts. Maximum nest counts for the former area from 1965 through 1969 were 163, 122, 282, 166, and 120, and for the latter area 78, 52, 147, 121, and 270. In 1965 and 1966 a few pairs bred in Scaevola southwest of the runway. Figure RFB-3 shows the general location of breeding areas in 1967 and 1968. As can be seen, many areas were not utilized although they appeared suitable, at least to humans.

Prior to the construction of the LORAN station, Red-footed Boobies bred in the Scaevola east of the south antenna field (Robbins, personal communication).

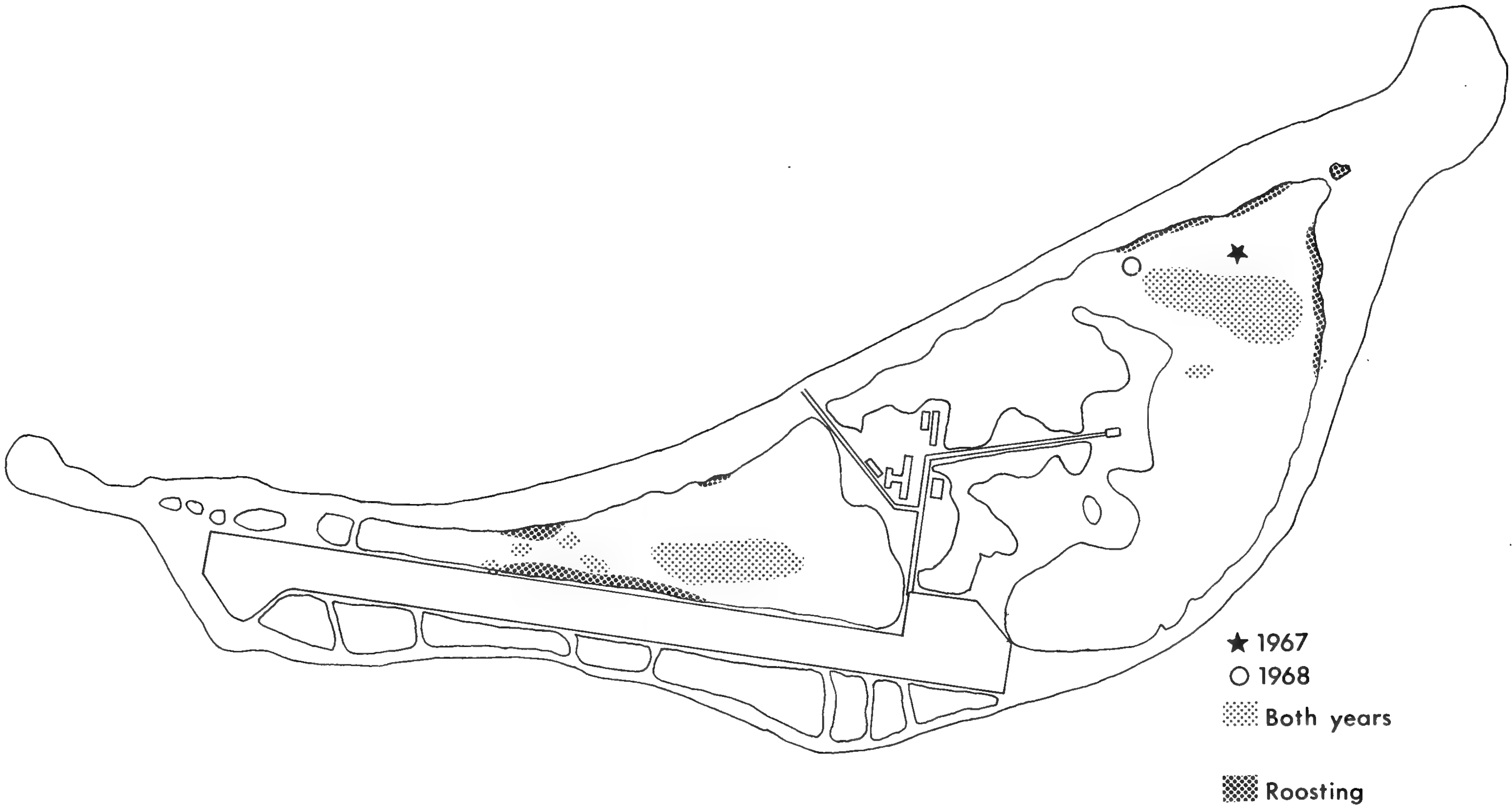

Figure RFB-3. Distribution of Red-footed Booby roosting and breeding areas on Green Island, Kure Atoll, 1967-68 (breeding areas were also roosting areas).

Non-breeding Red-footed Boobies roosted in the same general areas as the breeders. However, many also roosted along the beach-Scaevola ecotone. Sometimes these birds intermingled with the breeding birds, while at other times they formed groups by themselves. It was noted several times that when a nest was built in an area where Red-foots were previously absent, it soon became a focal point for roosting birds. Very few Red-foots roosted along the south beach, east beach, or on man-made structures. The main roosting areas are shown in Figure RFB-3.

Although breeding Red-foots landed on the ground while gathering nesting materials, none roosted there overnight. All breeding Red-footed Boobies at Kure were light-phase: all white with black flight feathers.

Banding and Movements

One thousand and eleven adult Red-footed Boobies were banded at Kure Atoll. Tables RFB-12-13 summarize the recapture of these birds at the atoll. Even though large numbers of Red-foots were usually handled each year (Table RFB-14), these recapture rates are low in comparison with the preceding two species where most individuals on the island were captured each year. Undoubtedly if all or most Red-foots had been handled each breeding season, the recapture rates would have been at least as high as the Brown Booby and possibly as high as the Blue-faced Booby.

Thirty-six of these adults were recaptured on other islands: 24 on Eastern Island, Midway Atoll, 3 at Pearl and Hermes Reef, 1 on Lisianski, 1 on Laysan, 6 on Sand Island, Johnston Atoll, and 1 on Wilkes Island, Wake Atoll. Interestingly, 10 of these Red-foots were recaptured again at Kure (4 from Midway, 2 from Pearl and Hermes, 3 from Johnston, and 1 from Wake), suggesting a type of migratory movement. Three of the birds captured at Midway Atoll bred there.

Four hundred and twenty-five subadult and 607 nestling Red-footed Boobies were banded at Kure Atoll. Tables RFB-15-16 summarize the recapture of these birds. As would be expected, fewer young Red-foots were recaptured than adults. However, more young traveled to other islands. Twenty-nine Red-footed Boobies banded as nestlings were recaptured at the following locations: 3 at Midway Atoll, 2 on Lisianski, 9 at French Frigate Shoals, and 15 at Johnston Atoll. Three of these birds were recaptured later at Kure (1 from Midway, 1 from French Frigate, and 1 from Johnston). The French Frigate Shoals Red-foot bred at Kure.

Twenty Red-footed Boobies banded as subadults were recaptured at the following locations: 6 at Midway Atoll, 1 at Pearl and Hermes Reef, 5 on Lisianski, 4 at French Frigate Shoals, and 4 at Johnston Atoll. Eight of these birds returned to Kure (4 from Midway Atoll, 1 from Lisianski, 2 from French Frigate, and 1 from Johnston). One Midway bird bred at Kure. The subadult Red-foot recaptured at Pearl and Hermes Reef was banded at Kure on 14 October 1963, recaptured on North Island

on 20 August 1964, and found dead at Taka Atoll, Marshall Islands, later that fall. No attempt to analyze this movement was made because of the great variation in the amount of effort expended in recapturing Red-foots on the various islands.

Table RFB-12. Recapture rates of adult Red-footed Boobies banded as breeders at Kure Atoll and recaptured there (expressed as percentages), 1964-69*.

Year Banded	n.	1964	1965	1966	1967	1968	1969
1964	32	100.0	43.8 (12.5)	40.6 (28.1)	28.1 (12.5)	21.9 (9.4)	18.8 (18.8)
1966	9	--	--	100.0	55.6 (11.1)	33.3 (33.3)	33.3 (33.3)
1967	58	--	--	--	100.0	44.8 (29.3)	22.4 (22.4)
1968	3	--	--	--	--	100.0	33.3 (33.3)
1969	8	--	--	--	--	--	100.0

(Columns 1964–1969: Year Recaptured)

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Enough Red-footed Boobies banded on other islands by the POBSP were recaptured at Kure from 1964 through June 1969, however, to permit a fairly detailed analysis of the nature of this movement. Table RFB-17 summarizes these data. Only Red-foots banded through 1968 are included in the totals. In addition, 4 Red-foots banded at Midway Atoll (2 as adults and 2 as nestlings) by non-POBSP personnel were captured at Kure.

To eliminate the differences between the number of birds banded on the various islands, the number of recaptures is expressed as a percentage of the total number of birds banded on a particular island. It is assumed that enough Red-foots of all ages were handled over a sufficiently long period to minimize any bias resulting from recapture techniques.

The final figures are a movement index of Red-foots from other islands to Kure. These data show or suggest the following: (1) Only Red-foots from the Hawaiian Islands, Wake, and Johnston traveled to Kure; (2) a greater percentage of young Red-foots traveled than adults; (3) movement indices for the Hawaiian chain decreased with increasing distance from Kure; (4) considerably more Red-foots from Wake and Johnston moved to Kure than would be expected if interisland movement were only a function of distance, suggesting that there may be a "migratory" movement between these areas. Too few data are available to determine yearly and seasonal differences.

Table RFB-13. Recapture rates of adult Red-footed Boobies banded as non-breeders at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	3	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1961	4	--	--	100.0	25.0 (0.0)	25.0 (0.0)	25.0 (0.0)	25.0 (0.0)	25.0 (0.0)	25.0 (0.0)	25.0 (25.0)	0.0 (0.0)
1962	27	--	--	--	100.0	44.4 (0.0)	44.4 (7.4)	37.0 (3.7)	37.0 (22.2)	22.2 (7.4)	14.8 (7.4)	11.1 (11.1)
1963	126	--	--	--	--	100.0	53.2 (8.7)	46.8 (10.3)	42.9 (28.6)	30.2 (13.5)	23.0 (11.1)	18.3 (18.3)
1964	249	--	--	--	--	--	100.0	58.6 (8.8)	55.8 (31.3)	40.2 (18.5)	32.9 (16.7)	22.5 (22.5)
1965	85	--	--	--	--	--	--	100.0	60.0 (41.2)	37.7 (18.8)	28.2 (16.5)	22.4 (22.4)
1966	290	--	--	--	--	--	--	--	100.0	44.5 (21.0)	34.1 (16.6)	24.5 (24.5)
1967	44	--	--	--	--	--	--	--	--	100.0	52.3 (22.7)	29.6 (29.6)
1968	77	--	--	--	--	--	--	--	--	--	100.0	32.5 (32.5)
1969	96	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table RFB-14. Number of Red-footed Boobies handled each year at Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
Breeding adults	0	36	0	18	150	41	85
Non-breeding adults	126	259	125	492	149	253	322
Subadults	74	88	12	190	75	114	69
Totals	200	383	137	700	374	408	476

Table RFB-15. Recapture rates of Red-footed Boobies banded as subadults at Kure Atoll and recaptured there (expressed as percentages), 1963-69*.

Year Banded	n.	Year Recaptured 1963	1964	1965	1966	1967	1968	1969
1963	74	100.0	43.2 (0.0)	41.9 (1.4)	39.2 (27.0)	25.7 (10.8)	17.6 (6.8)	13.5 (13.5)
1964	87	--	100.0	42.5 (0.0)	42.5 (27.6)	25.3 (11.5)	18.4 (16.1)	8.1 (8.1)
1965	11	--	--	100.0	27.3 (18.2)	27.3 (18.2)	18.2 (18.2)	0.0 (0.0)
1966	150	--	--	--	100.0	28.7 (21.3)	12.7 (6.3)	9.3 (9.3)
1967	35	--	--	--	--	100.0	20.0 (8.6)	11.4 (11.4)
1968	61	--	--	--	--	--	100.0	6.6 (6.6)
1969	7	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table RFB-16. Recapture rates of Red-footed Boobies banded as nestlings at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	28	100.0	3.6 (0.0)	3.6 (0.0)	3.6 (0.0)	3.6 (0.0)	3.6 (0.0)	3.6 (0.0)	3.6 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1962	71	--	--	--	100.0	19.7 (0.0)	19.7 (0.0)	19.7 (1.4)	19.7 (11.3)	14.1 (7.0)	9.9 (4.2)	7.0 (7.0)
1964	9	--	--	--	--	--	100.0	55.6 (11.1)	44.4 (22.2)	22.2 (22.2)	11.1 (11.1)	0.0 (0.0)
1966	127	--	--	--	--	--	--	--	100.0	24.4 (3.9)	22.1 (18.1)	6.3 (6.3)
1967	141	--	--	--	--	--	--	--	--	100.0	14.9 (11.4)	5.0 (5.0)
1968	198	--	--	--	--	--	--	--	--	--	100.0	1.5 (1.5)
1969	33	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table RFB-17. Movement of Red-footed Boobies banded by the POBSP on other islands to Kure Atoll, 1964-69.

From:	Midway Atoll	Pearl and Hermes Reef	Lisianski	Laysan	French Frigate Shoals	Johnston Atoll	Wake Atoll	Main Hawaiian Is.
Distance (naut. miles)	49	135	266	379	695	838	978	1,072
Number adults banded	174	150	664	604	617	153	144	2,441
Number young* banded	159	18	199	256	1,168	646	320	1,703
Total number banded	333	168	863	860	1,785	799	464	4,144
Number banded as adults recaptured at Kure	4	3	0	1	3	3	1	0
Number banded as young recaptured at Kure	18	2	6	5	10	12	15	3
Total number recaptured at Kure	22	5	6	6	13	15	16	3
% banded as adults recaptured at Kure	2.3	2.0	0.0	0.2	0.5	2.0	0.7	0.0
% banded as young recaptured at Kure	11.3	11.1	3.0	2.0	0.9	1.9	4.7	0.2
% of all birds banded recaptured at Kure	6.6	3.0	0.7	0.7	0.7	1.9	3.4	0.1

* Includes nestlings, immatures and subadults.

GREAT FRIGATEBIRD *Fregata minor*

Status

Abundant late winter-summer breeder; 120 to 400 pairs annually. Present all year with peak numbers present from May through mid-July. Breeding begins in late February and continues to mid-December.

Populations

Apparently the Great Frigatebird population did not decrease as a result of the construction of the LORAN station; earlier estimates (Table GF-1) were no higher than POBSP estimates (Table GF-2). Although *Scaevola* covered considerably more area in 1915 and 1923 than in the 1960's, Munter and Wetmore's observations indicated that this species bred in only a small portion of the available habitat. Even today Great Frigatebirds do not roost or breed in all the available *Scaevola*.

Table GF-1. Previous records of Great Frigatebirds on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	1,000	1 colony near center of island; eggs (Munter, 1915: 137).
1923	April 17-22	200	100 pairs nesting in *Scaevola* near central plain (Wetmore, ms.).
1957	June 5	325	100 nests estimated; roosting in *Scaevola*; 3 concentrations between central plain and southeast beach (Kenyon and Rice, 1958: 190).
1959	October 3-8	275	Nesting (Robbins, 1966: 53).
1960	March 28	800	Nesting (Robbins, 1966: 53).
1961	January 19-21	40	None nesting (Robbins, 1966: 53).
	September 12-14	?	Nesting (Udvardy and Warner, 1964: 2).
1962	February 2-4	50	None nesting (Robbins, 1966: 53).
	August 6-8	250	115 nests (Robbins, 1966: 53).
1963	February 3-7	100	Not nesting (Robbins, 1966: 53).

Table GF-2. POBSP semi-monthly estimates of Great Frigatebirds on Green Island, Kure Atoll, 1964-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	250	100	-	15	-	350
16-31	-	250	200	-	-	-	400
February							
1-15	-	*	300	160	70	-	250
16-28	*	650	300	-	-	-	250
March							
1-15	-	750	700	-	-	-	300
16-31	-	750	700	-	*	450	500
April							
1-15	-	750	550	-	-	-	500
16-30	-	750	550	600	-	-	600
May							
1-15	900	750	550	700	1,500	-	800
16-31	-	750	550	700	1,500	1,000	850
June							
1-15	-	750	1,000	700	1,500	1,000	1,500
16-30	-	750	800	600	1,500	1,000	*
July							
1-15	-	500	750	300	1,500	600	-
16-31	-	1,100	750	250	-	600	-
August							
1-15	-	1,000	700	225	-	500	-
16-31	-	950	-	300	-	500	-
September							
1-15	-	1,050	-	120	-	300	-
16-30	*	1,100	-	325	-	300	-
October							
1-15	*	1,100	-	-	-	500	-
16-31	*	1,100	-	-	-	500	-
November							
1-15	400	1,300	-	-	-	300	-
16-30	400	700	300	-	-	300	-
December							
1-15	250	700	450	-	-	100	-
16-31	700	197	-	15	-	*	-

* Birds present, number unknown.

The most accurate population data were nest counts made in 1965, 1967, 1968, and 1969 which revealed minimum breeding populations of 532, 512, 240, and 380, respectively. The 1967 and 1968 counts were conservative since they were made in May when a large number of nests probably had already been destroyed. These data were insufficient to determine if there was any significant change in the size of the breeding population during POBSP studies. If Great Frigatebirds breed only every other year as some authors (e.g., Nelson, 1967; Schreiber and Ashmole, 1970) suggest, then the total Kure breeding population was 1,000 to 1,100 individuals.

Generally POBSP estimates were based on roost counts and therefore were accurate only in a general way. The limitations of these counts were discussed in the Red-footed Booby account. Enough banding data were collected in 1966 and 1967, however, to analyze the structure of, and to characterize, the Kure Great Frigatebird population. Tables GF-3 and 4 summarize the data. It was assumed that enough birds were handled to eliminate any bias resulting from the recapture technique; therefore, these samples are representative.

It is evident that approximately equal numbers of adults and subadults were present, that only a small percentage of the population was banded, and that many of the banded birds were from other islands. These facts suggest a high turnover rate. For example, in 1966 only 12.2 percent of the adults and 7.3 percent of the subadults banded previously at Kure were captured. In 1967 only 5.1 percent of the adults and 2.8 percent of the subadults banded in 1966 were found. Since 318 frigatebirds were banded prior to 1966 and 561 in 1966, the total number of birds using the island during a year must be in the thousands. A simple Lincoln Index calculation shows this.

Prior to 1967, 879 Great Frigatebirds were banded at Kure. In 1967, 429 frigatebirds were handled; 49 had been banded previously at Kure. Therefore:

$$\frac{879}{x} = \frac{49}{429} \qquad \text{where } x = \text{total island population.}$$

Therefore, x = 7,700. Although this figure is probably too high, it indicates that the Kure population numbers in the thousands. If this is true, then most of the frigatebirds using the island are non-breeders. The relatively large numbers of interisland birds (56 or 34.4 percent of all banded birds captured) also showed the transitory nature of the population.

An interesting and unexplained feature of the subadult population was the preponderance of females. In 1967, 151 subadults were sexed by bill measurements (♂♂ less than 110 mm., ♀♀ greater than 112 mm, POBSP, unpublished). Of these, 49 (32.5 percent) were males and 102 (67.5 percent) were females. Further work will be necessary to determine the significance of this observation.

Table GF-3. Summary of Great Frigatebirds handled on Green Island, Kure Atoll, April-October 1966.

	Adults	Subadults	Total
Total number handled	277	264	541
Number banded	255	228	483
Number previously banded on Kure	15	15	30
Number previously banded on other islands	7	21	28
% banded	7.9	13.6	10.7
% interisland (figure in parentheses is percent of banded birds)	2.5 (31.8)	8.0 (58.3)	5.2 (48.3)

Table GF-4. Summary of Great Frigatebirds handled on Green Island, Kure Atoll, 5 May-8 July 1967.

	Adults	Subadults	Total
Total number handled	213	216	429
Number banded	178	182	360
Number previously banded on Kure	30	19	49
Number previously banded on other islands	5	15	20
% banded	16.4	15.7	16.1
% interisland (figure in parentheses is percent of banded birds)	2.3 (14.3)	6.9 (44.1)	4.7 (29.0)

Annual Cycle

Great Frigatebirds were present throughout the year with peak populations present from May through at least mid-July. POBSP data suggest that there was a general exodus from the atoll during the winter.

The first indication of a new Great Frigatebird breeding cycle was the reddening and enlargement of the male's gular sac, usually in November. By late December or January males began sitting in Scaevola, inflating their gular sacs, and calling to females overhead. Courtship activity was intense from at least late January through April, and some males with inflated gular sacs were seen into late May.

Great Frigatebirds bred on a fairly rigid schedule, although there were some yearly differences in the timing of peak egg laying (Table GF-5). The most accurate data were obtained in 1965 and from 1967 to

Table GF-5. Major periods in the Great Frigatebird breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	21 February-July?	Late February-early June	? - May	Early March-May	Early March-early May	Early March-at least early May
Peak Egg Laying	Probably March or April	Last 2 weeks April	Early May	First 2 weeks April	Late March-3rd week April	Mid-March-mid-April
Hatching	Early April-July	Late April?-mid-July	At least April	Mid-April-early July	Late April-early July	Early May-?
Peak Hatching	Probably May or June	First 2 weeks June	?	Last 2 weeks May	Late May-mid-June	?
Fledging	September-December	Late September-mid-December	September	Mid-September-early December	Late September-early December	?

1969. Figure GF-1 summarizes the 1965, 1968, and 1969 data, while Table GF-6 compares the 1967 and 1968 nest counts.

Eggs were first laid in late February or early March, and a few were laid at least as late as early June. The peak period of egg laying was usually in April. Eggs began hatching in early April and some hatched as late as mid-July. The peak period of hatching was in late May or June. Young frigatebirds began to fly as early as September and the last ones fledged in December. At least some of these young birds remained in the colony until the following June.

Table GF-6. Comparison of 1967 and 1968 Great Frigatebird nest counts on Green Island, Kure Atoll.

	1967		1968	
Date	Number of nests	% with eggs	Number of nests	% with eggs
May 9	202	?		
17	256	67.0		
24	239	50.2		
29			120	47.5
June 6			101	36.4
14			91	13.8
19	185	23.1		

Nesting Success

Table GF-7 summarizes Great Frigatebird productivity from 1964 to 1969. The exact causes for the almost complete nesting failure in 1966 are unknown, but it may have been rat predation. At least six adult Great Frigatebirds with typical rat wounds on the back were found that year. However, no rats were actually seen attacking adults or nestlings.

Although no detailed breeding studies were conducted, it was evident that a considerable number of nests were destroyed by unknown causes, most likely by the breeding adults. For example, from mid-May to mid-June 1967 *ca*. 23.8 percent of all nests disappeared.

Ecology

The main Great Frigatebird breeding area was in the north roost within 50 yards of the northernmost *Tournefortia* along the northeast beach. In 1964 large numbers bred in the central roost, but during the next two years none bred there; in 1967 only three pairs, in 1968 only six pairs, and in 1969, 26 pairs were found in this area. Figure GF-2 shows the general breeding areas in 1967 and 1968. In the latter year at least eight pairs bred in the *Scaevola* *ca*. 10 yards east of the

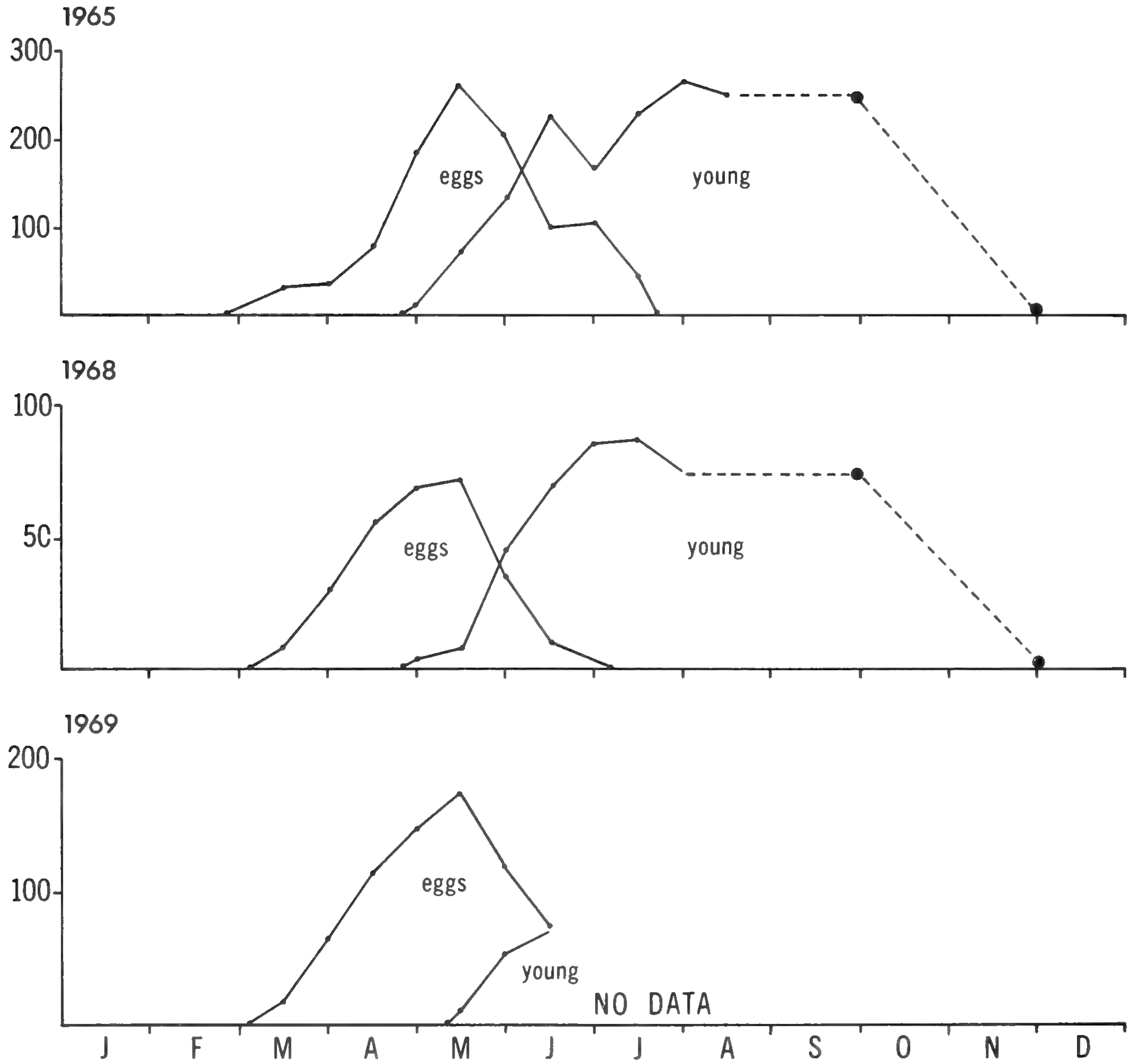

Figure GF-1. Breeding cycles of Great Frigatebirds on Green Island, Kure Atoll, 1965, 1968, 1969.

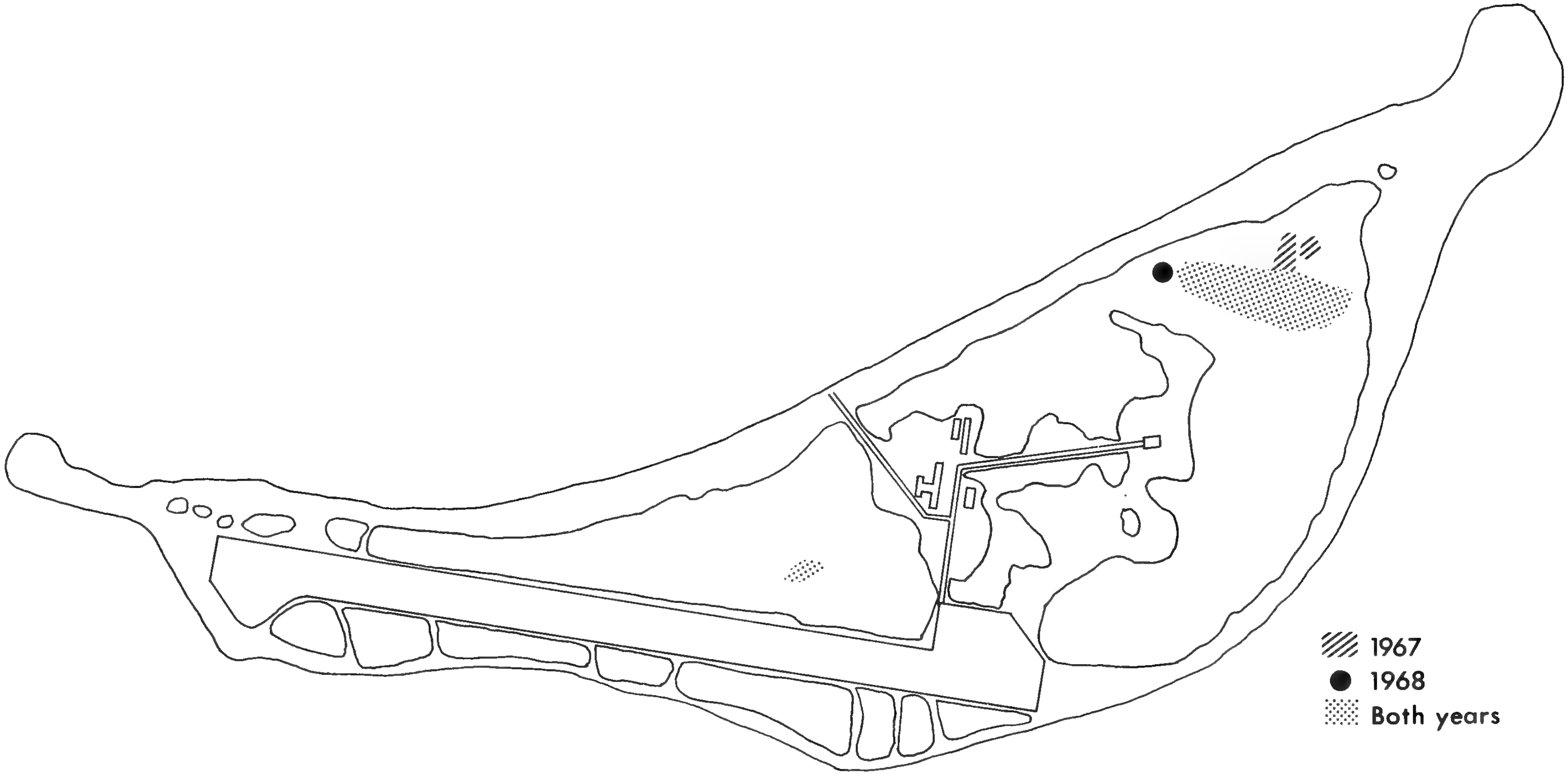

Figure GF-2. Distribution of Great Frigatebird breeding areas on Green Island, Kure Atoll, 1967-68.

Table GF-7. Great Frigatebird productivity on Green Island, Kure Atoll, 1964-69.

Year	Maximum Nest Count or Estimate	Approximate Number of Young Fledged	Percent Fledged
1964	400[1]	200	50.0
1965	266	250[2]	94.0
1966	200	1	0.5
1967	256	185[3]	72.4
1968	120	77[4]	64.3
1969	190	75[5]	--

[1] Probably too large. [2] Number remaining in mid-August.

[3] Number remaining in mid-June. [4] Number remaining in early August.

[5] Number remaining in late June; 75 eggs had not yet hatched.

north tower, an area that had not been utilized previously. Prior to the construction of the LORAN station, this species bred along the east edge of the south antenna field (Robbins, personal communication).

Usually Great Frigatebirds bred in small groups with other frigatebirds or among Red-footed Boobies. The distance between nests was determined by the availability of nest sites and by the range of the incubating bird's bill, nests being just out of a neighbor's reach. For the most part, nests were placed in the center of vegetated areas rather than along the edges.

Great Frigatebirds bred mainly in Scaevola, and also in Tournefortia. Here they built bulky nests of Solanum vines with the addition of some Ipomoea and Boerhavia. Males gathered these materials while flying over open areas, mainly the central plain. Nests were built by placing the vines on a supporting platform of branches; sometimes these branches were on the same bush and at other times were on interlocking branches of different bushes. Unlike Red-footed Boobies, frigatebirds always placed nests near the top of the vegetation where there was enough area overhead for the adults, with their large wingspan, to take off and land easily. The height of the nests from the ground ranged from three to at least eight feet, depending on the height of the vegetation. In 1967, 10 nests were an average of 50.1 inches from the ground and had an average diameter of 12 inches. Only a slight depression was formed by adults incubating the single egg.

The main roosting areas for Great Frigatebirds were in the Casuarina west of the power plant, along the northwest beach from the north tower to the north point (including the north tower), along the northeast beach north of the central plain, among breeding Great Frigatebirds in the north

roost, among breeding Red-footed Boobies in the central roost, and along the southwest beach south of the casuarinas. Occasionally they roosted along the southeast beach and on the LORAN guywires. They usually roosted in small groups with other Great Frigatebirds or with Red-footed Boobies. Scaevola was the dominant roosting site, followed by Casuarina and Tournefortia. Roost sites varied considerably from day to day. For example, one night large numbers roosted along the northwest beach while the next night almost none was present there. Active nests became the focal point for much of the nocturnal roosting and these sites were subject to less daily variation.

Banding and Movements

Seven hundred and three adult Great Frigatebirds were banded at Kure Atoll. Compared with the Red-footed Booby, relatively few of these birds were recaptured at the atoll (Table GF-8), again suggesting the highly transitory nature of this species.

Four Great Frigatebirds banded as adult females were captured on other islands in the central Pacific: 2 on Eastern Island, Midway Atoll, 1 on Lisianski, and 1 on East Island, French Frigate Shoals. None was recaptured again at Kure.

Seven hundred and seventy-one subadult Great Frigatebirds were also banded. Although relatively large numbers of frigatebirds were handled, especially in 1966 and 1967 (Table GF-9), few subadults were recaptured (Table GF-10). However, over twice as many birds banded as subadults were recaptured on other islands than adults: 1 on Southeast Island, Pearl and Hermes Reef, 2 on Lisianski, 1 on Laysan, and 7 at French Frigate Shoals, including 1 that returned to Kure.

Robbins banded 95 nestling Great Frigatebirds (48 in 1959, 10 in 1961, and 37 in 1962). Three of the 1959 cohort were recaptured (1 in 1965, 1 in 1966, and 1 in 1967) and 2 of the 1962 cohort (2 in 1966 and 1 again in 1968) were also recaptured.

The POBSP banded 170 nestlings (29 in 1965, 113 in 1967, and 28 in 1968). Three of the 1965 cohort, 8 of the 1967 cohort, and 6 of the 1968 cohort were recaptured the year after banding. Two of these Great Frigatebird nestlings banded in 1965 were found at Midway Atoll in early 1966.

Six Great Frigatebirds banded at Kure were recovered outside the central Pacific (Table GF-11). These data show that after breeding some adult frigatebirds traveled to the western Pacific.

Movement of previously banded frigatebirds to Kure was analyzed in the same manner as movement of Red-footed Boobies (Table GF-12). In addition, 2 Great Frigatebirds banded at Midway Atoll (1 as a nestling and 1 as adult male) by non-POBSP personnel were found breeding at Kure Atoll. It is evident that there was decreasing movement, on a percentage

Table GF-8. Recapture rates of Great Frigatebirds banded as adults at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	2	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1962	5	--	--	--	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1963	34	--	--	--	--	100.0	38.2 (0.0)	38.2 (2.9)	38.2 (20.6)	26.5 (20.6)	14.7 (8.8)	5.9 (5.9)
1964	64	--	--	--	--	--	100.0	18.8 (1.6)	17.2 (12.5)	7.8 (6.3)	3.1 (1.6)	3.1 (3.1)
1965	25	--	--	--	--	--	--	100.0	12.0 (12.0)	12.0 (12.0)	4.0 (0.0)	4.0 (4.0)
1966	235	--	--	--	--	--	--	--	100.0	11.5 (5.1)	7.3 (2.1)	4.7 (4.7)
1967	169	--	--	--	--	--	--	--	--	100.0	6.5 (4.1)	2.4 (2.4)
1968	64	--	--	--	--	--	--	--	--	--	100.0	4.8 (4.8)
1969	105	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

basis, with increasing distance from the atoll, and that young birds traveled more frequently than adults. The relatively large volume of movement from Pearl and Hermes Reef probably resulted from an insufficient supply of roosting sites at that atoll. All Great Frigatebirds banded as nestlings on other islands captured at Kure Atoll were taken at least two years after banding, indicating they remained in the breeding colonies for at least a year after hatching.

Table GF-9. Number of Great Frigatebirds handled each year at Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
Breeding adults	0	0	0	6	22	1	37
Non-breeding adults	34	64	26	257	182	73	101
Subadults	56	70	81	319	216	62	69
Totals	90	134	107	582	420	136	207

LESSER FRIGATEBIRD — *Fregata ariel*

On 27 May 1967 Woodward saw an adult female Lesser Frigatebird flying over the north roost and later roosting in *Scaevola* among Red-footed Boobies and Great Frigatebirds. The bird was collected later in the day. Although the brood patch was bare, there was no indication that this bird was breeding.

Another adult female was captured the night of 25 June 1968 as it roosted with five Great Frigatebirds at the edge of *Scaevola* along the northwest beach. The next day it was banded, photographed, and released.

Lesser Frigatebirds occur abundantly in the central Pacific south of Johnston Atoll. They breed on many islands of the Phoenix and Line Groups, and, to an unknown, extent, in the Tuamotu and Marquesas groups (Sibley and Clapp, 1967). There are the first records for the Northwestern Hawaiian Islands.

BLACK-CROWNED NIGHT HERON — *Nycticorax nycticorax* (*hoactli*?)

Woodward found the remains of an adult Black-crowned Night Heron under *Scaevola* in the northeast Sooty Tern colony on 3 June 1966.

The race *N. n. hoactli* breeds in the Main Hawaiian Islands and has wandered previously to Midway Atoll (Clapp and Woodward, 1968).

Table GF-10. Recapture rates of Great Frigatebirds banded as subadults at Kure Atoll and recaptured there (expressed as percentages), 1961-69*.

Year Banded	n.	Year Recaptured 1961	1962	1963	1964	1965	1966	1967	1968	1969
1961	1	100.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1963	56	--	--	100.0	21.4 (1.8)	21.4 (3.6)	17.9 (10.7)	7.1 (7.1)	0.0 (0.0)	0.0 (0.0)
1964	69	--	--	--	100.0	20.3 (1.5)	18.8 (8.7)	10.1 (4.4)	7.3 (5.8)	1.5 (1.5)
1965	77	--	--	--	--	100.0	7.8 (2.6)	6.5 (2.6)	2.6 (2.6)	0.0 (0.0)
1966	281	--	--	--	--	--	100.0	6.8 (3.6)	2.1 (1.1)	1.4 (1.4)
1967	182	--	--	--	--	--	--	100.0	1.7 (1.1)	0.6 (0.6)
1968	42	--	--	--	--	--	--	--	100.0	0.0 (0.0)
1969	63	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table GF-11. Great Frigatebirds banded at Kure Atoll and recovered at various locations.

Date Banded	Age and Sex at Time of Banding	Where Found	When Found
7 October 1959	Nestling	Philippines: Luzon: Camarines Sur: Lagonoy Gulf: Sagnay	10 November 1960
11 August 1964	Adult ♀	Philippines: Mindanao: Matanao: Barrio Banghal	10 March 1965
9 August 1964	Adult ♀	Philippines: Negros: Bacolod	8 March 1966
10 June 1966*	Adult ♀	Philippines: Samar: Bobon	12 December 1967
25 June 1966	Subadult	Marshall Islands: Ugelang Atoll	14 February 1967
14 October 1963**	Adult ♀	Marshall Islands: Eniwetok Atoll: James Island	18 March 1969

* Recaptured at Kure on 2 July 1967.
** Recaptured at Kure on 21 July 1966, 3 July 1967, and 30 May 1968.

EMPEROR GOOSE *Philacte canagica*

Kleen caught a female Emperor Goose on 15 December 1968 as it sat along the beach near the east end of the runway.

No Emperor Geese have been recorded previously from the Northwestern Hawaiian Islands, but their occurrence has been well-documented in the Main Hawaiian Islands on four previous occasions (Clapp, *et al*., 1969).

EUROPEAN WIDGEON *Mareca penelope*

An emaciated second winter female European Widgeon was captured by Coast Guard personnel on 10 November 1964 near the east end of the runway. Lewis saw another individual on 12 November 1965 feeding near the fuel tanks. He collected it two days later. It proved to be a first winter female. These records and one for Midway Atoll are the only ones for the Hawaiian Islands (Clapp and Woodward, 1968).

Table GF-12. Movement of Great Frigatebirds banded by the POBSP on other islands to Kure Atoll, 1964-69.

From:	Midway Atoll	Pearl and Hermes Reef	Lisianski	Laysan	French Frigate Shoals	Johnston Atoll	Nihoa
Distance (naut. miles)	49	135	266	379	695	838	926
Number adults banded	11	230	242	283	1,060	541	1
Number young* banded	3	299	179	231	1,052	283	490
Total number banded	14	529	421	514	2,112	824	491
Number banded as adults recaptured at Kure	1	17	2	2	1	1	0
Number banded as young recaptured at Kure	0	25	1	3	9	3	1
Total number recaptured at Kure	1	42	3	5	10	4	1
% banded as adults recaptured at Kure	9.1	7.4	0.8	0.7	0.1	0.2	0.0
% banded as young recaptured at Kure	0.0	8.4	0.6	1.3	0.9	1.1	0.2
% of all birds banded recaptured at Kure	7.1	7.9	0.7	1.0	0.5	0.5	0.2

* Includes nestlings, immatures and subadults.

PINTAIL *Anas acuta*

Robbins photographed a Pintail 3 to 8 October 1959 and found a carcass on 3 February 1962 (Robbins, 1966: 53). These were the first known records for the atoll.

Subsequent POBSP records include: a female collected on 1 October 1963 along the road by the barracks; a male shot on 7 November 1964; two males collected on 17 March 1965 and 19 March 1965; a male collected on 22 September 1966 in the north antenna field, and a male collected on 26 November 1968. The March 1965 Pintails, both in breeding plumage, were first seen with a female in a flood pond along the runway on 17 March.

This species breeds across most of the northern half of the Northern Hemisphere (AOU, 1957) and winters regularly in the main Hawaiian Islands (Medeiros, 1958).

TUFTED DUCK *Aythya fuligula*

On 29 October 1963 Wirtz caught an immature female Tufted Duck near the barracks. Two other ducks believed to be this species were also seen, one on 30 October 1963 and one on 18 September 1964.

Tufted Ducks have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll (Clapp and Woodward, 1968).

BUFFLEHEAD *Bucephala albeola*

DeLong saw an adult female or immature Bufflehead on 12 November 1968 by the barracks. He saw it several times the following week, but was unable to collect it.

Buffleheads are casual visitors to the Hawaiian Islands (AOU, 1957).

Table D-1 summarizes sightings of unidentified ducks made at Kure Atoll.

Table D-1. Summary of unidentified ducks seen on Green Island, Kure Atoll, 1963-68.

Date Seen		Number	Remarks
1963	September 30	1	--
	October 1	1	In lagoon
	October 6	1	--
	October 7	1	Landed in antenna field.

Table D-1. (continued)

Date Seen		Number	Remarks
1963	October 18	1	--
	October 28	1	--
	October 29	1	--
	October 30	1	--
	November 12	1	In puddle near fuel tanks.
1964	September 24	4	Flying over lagoon.
	November 5	1	Landed on east beach.
1968	August 29	1	Near north point.
	August 31	1	--
	September 28	1	Along northwest beach.

PEREGRINE FALCON *Falco peregrinus* (*pealei*?)

Standen shot a female Peregrine Falcon on 7 March 1965 as it flew over *Scaevola* near the radar reflector. Dr. Clayton M. White identified the specimen as *F. p. pealei* on the basis of the extremely heavily marked flanks and thighs; in every other regard the specimen matches the darker examples of *F. p. japonensis* (Clapp and Woodward, 1968).

This specimen and sight records from Midway Atoll and Lisianski are the only records of Peregrines in the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

DOTTEREL *Eudromias morinellus*

An immature female Dotterel was caught on 9 September 1964 in a mist net erected on the station grounds. This bird had been seen flying with a flock of American Golden Plovers for several days before it was collected. This is the only record for the Hawaiian Islands (Clapp and Woodward, 1968).

AMERICAN GOLDEN PLOVER *Pluvialis dominica*

Status

Common spring and fall migrant; common winter resident; uncommon summer resident. Populations ranged from 3 to 250 individuals. At least a few present in every month.

Populations

Only one pre-POBSP estimate (Table AGP-1) was larger than POBSP estimates (Table AGP-2) of American Golden Plovers.

POBSP estimates indicated plover populations ranging from 3 to 250 individuals. The 1965 and 1969 estimates were similar, but smaller than the 1964 estimate. It is difficult to determine if these differences are significant since there are many variables (*e.g.*, time of day, tide conditions, weather conditions) that could affect the number of birds counted on any given day. If the population did decrease, it probably was the result of conditions on the breeding grounds rather than conditions at Kure where no significant habitat changes occurred from 1964 to 1969.

Annual Cycle

Figure AGP-1 presents graphically the annual population cycle based on semi-monthly estimates and observations of Golden Plovers at the atoll. At least a few were present every month but they were common only from late August to mid-May. This species apparently migrated from March through June, and mid-August through at least October.

Ecology

Golden Plovers occurred commonly in the open areas, both in the interior and along the beaches. Table AGP-3 lists by season the percentage and location of plovers seen on shorebird counts from 1963 to 1965. Plovers were more common in the interior than along the beaches. During the winter a few Golden Plovers established territories near the barracks.

The main seasonal distributional changes were a greater abundance on the beaches and along the runway in the fall, and a decrease in abundance in the central plain during the summer.

Golden Plovers commonly occurred in pure flocks or with Ruddy Turnstones, and occasionally with Wandering Tattlers or Sanderlings. Unfortunately, numerical data on species association were not obtained.

Table AGP-1. Previous records of American Golden Plovers on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Remarks and References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	fairly common	Found in central plain with turnstone and on the beaches (Wetmore, ms.).
1957	June 5	2	Along north shore (Kenyon and Rice, 1958: 190).
1958	May 9	2	On beaches (Rice, pers. corr.).
1959	October 3-8	25	(Robbins, 1966: 53).
1960	March 28	25	(Robbins, 1966: 53).
1961	January 19-21	50	(Robbins, 1966: 53).
	September 12-14	14	On runway and beach (Udvardy and Warner, 1964: 2).
1962	February 2-4	500	(Robbins, 1966: 53).
	August 6-8	55	(Robbins, 1966: 53).
1963	February 3-7	20	(Robbins, 1966: 53).

Banding and Movements

The POBSP banded 88 American Golden Plovers and Robbins banded 13 (Table AGP-4). Two of these individuals were recovered on the island at a later date; one banded on 12 November 1963 was collected on 30 April 1967, and one banded on 20 October 1964 was captured on 2 March 1965. In addition, one banded on 31 October 1963 was found dead on Sand Island, Midway Atoll, on 1 March 1966.

An adult Golden Plover banded at Zapadni on St. George in the Pribilof Islands on 8 August 1966 was collected on Green Island 26 days later. Another banded on Lisianski by Eugene Kridler on 11 March 1964 was mist netted at Kure on 1 September 1964.

Table AGP-2. POBSP semi-monthly estimates of American Golden Plovers on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	75	71	-	40	-	60
16-31	-	75	52	-	-	-	50
February							
1-15	-	*	56	70	*	-	40
16-28	*	87	46	-	-	-	35
March							
1-15	-	65	50	-	-	-	35
16-31	-	137	38	-	12	-	40
April							
1-15	-	87	44	-	-	-	40
16-30	-	87	51	46	-	-	35
May							
1-15	40	87	45	13	20	-	25
16-31	-	6	20	12	12	-	10
June							
1-15	-	37	20	12	7	4	10
16-30	-	41	21	21	14	7	*
July							
1-15	-	30	20	15	-	3	-
16-31	-	13	20	14	-	3	-
August							
1-15	-	33	30	13	-	20	-
16-31	-	72	-	57	-	20	-
September							
1-15	-	100	-	40	-	40	-
16-30	*	121	-	67	-	55	-
October							
1-15	*	136	-	-	-	50	-
16-31	*	87	-	-	-	50	-
November							
1-15	250	95	-	-	-	50	-
16-30	75	75	65	-	-	50	-
December							
1-15	63	85	65	-	-	50	-
16-31	70	80	-	40	-	55	-

* Birds present, number unknown.

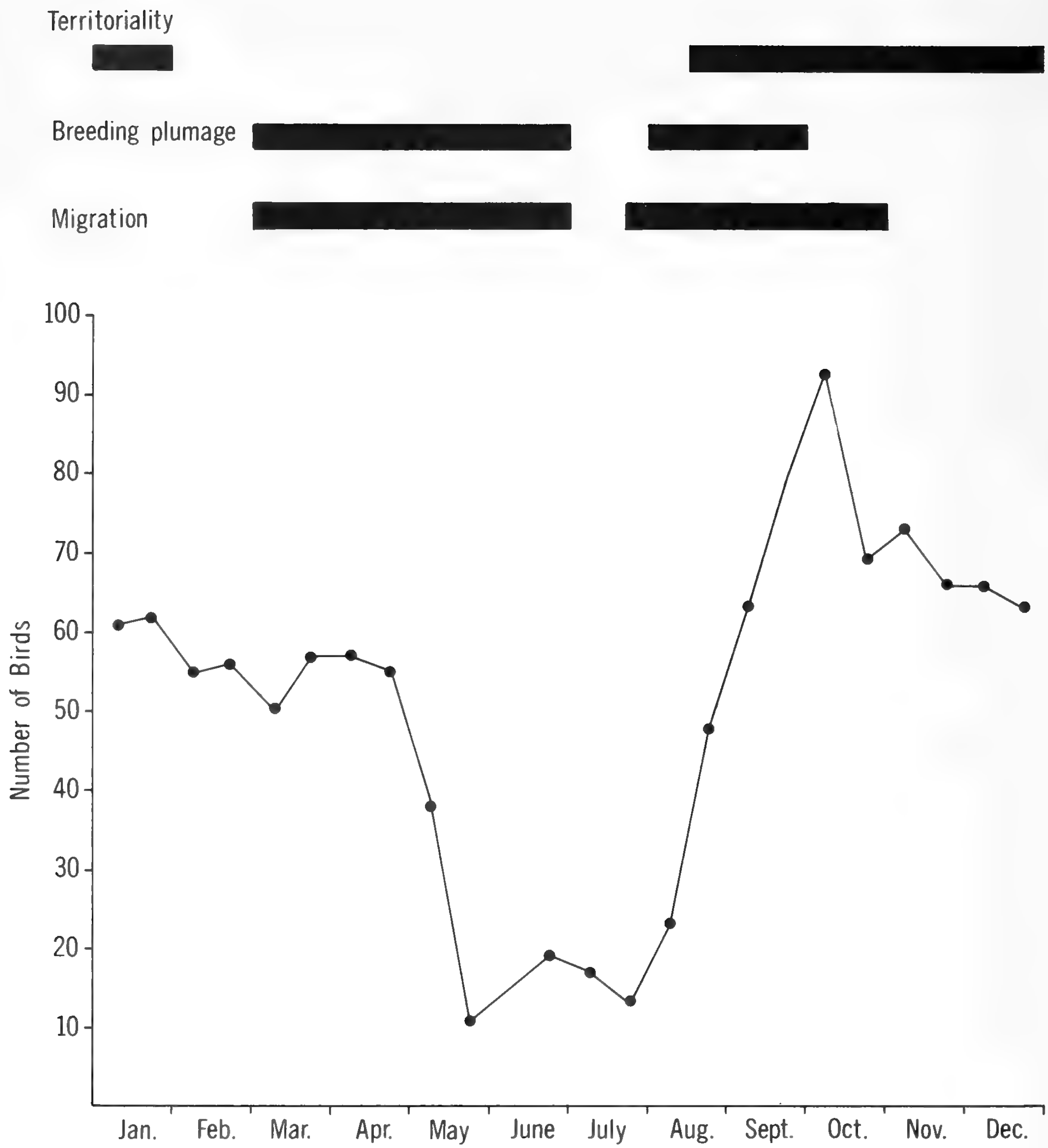

Figure AGP-1. Annual cycle of American Golden Plovers on Green Island, Kure Atoll (based on semi-monthly estimates).

Table APG-3. Percentage of American Golden Plovers recorded by season in different areas on Green Island, Kure Atoll, during 1963-65 shorebird counts.

Area	Winter	Spring	Summer	Fall
Ocean beach	11.3	5.3	10.1	4.8
Lagoon beach	9.1	9.3	28.4	23.0
North point	0.4	1.0	0.2	0.7
West point	4.4	6.9	1.4	2.1
Runway	9.6	11.9	10.6	42.1
Central plain	18.7	18.1	2.4	12.5
Rest of interior	46.5	47.5	46.9	14.8

Table AGP-4. American Golden Plovers banded at Kure Atoll.

Year Banded	Adults	Immatures	Unknown	Totals
1959	4	8	0	12
1962	0	0	1	1
1963	0	0	37	37
1964	0	0	43	43
1965	0	0	4	4
1966	0	0	3	3
1967	0	0	1	1
Totals	4	8	89	101

BLACK-BELLIED PLOVER *Squatarola squatarola*

Single Black-bellied Plovers were seen on 19 and 23 October 1963 and 20 May 1964. The latter was at the east end of the runway.

Black-bellied Plovers, which are found infrequently in the Northwestern Hawaiian Islands, have also been recorded from Midway Atoll, Lisianski, and Laysan (Clapp and Woodward, 1968).

RUDDY TURNSTONE *Arenaria interpres*

Status

Common migrant and winter resident, uncommon summer resident. Populations ranged from 2 to 150 birds. Most abundant in spring and fall. Least common in summer.

Populations

Comparison of pre-POBSP observations (Table RT-1) and POBSP estimates (Table RT-2) reveal no significant differences in the size of the Ruddy Turnstone population, nor were significant differences observed during the course of POBSP studies. These data indicate population on the island at any one time of 70 to 150 during periods of peak abundance, and 2 to 20 during periods of minimal abundance. It was not determined how many turnstones used the island during the year, although it was probably considerably more than the maximum estimate.

Table RT-1. Previous records of Ruddy Turnstones on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Remarks and References
1915	March 28	100	Small flocks along the shore (Munter, 1915: 137).
1923	April 17-22	common	Found in central plain and under dense Scaevola (Wetmore, ms.).
1957	June 5	3	Along north beach (Kenyon and Rice, 1958: 190).
1958	May 9	7	(Rice, pers. corr.).
1959	October 3-8	50	(Robbins, 1966: 53).
1960	March 28	50	(Robbins, 1966: 53).
1961	January 19-21	150	(Robbins, 1966: 53).
	September 12-14	35-40	Groups on beach (Udvardy and Warner, 1964: 2).
1962	February 2-4	125	(Robbins, 1966: 53).
	August 6-8	20	(Robbins, 1966: 53).
1963	February 3-7	27	(Robbins, 1966: 53).

Annual Cycle

Figure RT-1 presents graphically the annual population cycle, based on semi-monthly estimates and observations, of Ruddy Turnstones at the atoll. At least a few turnstones were present every month but they were

Table RT-2. POBSP semi-monthly estimates of Ruddy Turnstones on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	75	125	-	50	-	150
16-31	-	75	79	-	-	-	80
February							
1-15	-	*	83	50	*	-	60
16-28	*	112	107	-	-	-	70
March							
1-15	-	87	105	-	-	-	100
16-31	-	87	90	-	39	36	120
April							
1-15	-	87	66	-	-	-	76
16-30	-	87	47	51	-	-	80
May							
1-15	10	40	25	26	43	-	50
16-31	-	4	25	27	21	12	20
June							
1-15	-	11	30	2	20	14	4
16-30	-	13	30	29	16	10	*
July							
1-15	-	15	30	14	-	16	-
16-31	-	21	20	12	-	36	-
August							
1-15	-	76	40	51	-	60	-
16-31	-	85	-	120	-	50	-
September							
1-15	-	86	-	75	-	90	-
16-30	*	92	-	56	-	90	-
October							
1-15	*	41	-	-	-	*	-
16-31	*	86	-	-	-	*	-
November							
1-15	150	145	-	-	-	*	-
16-30	75	100	80	-	-	*	-
December							
1-15	50	105	80	-	-	*	-
16-31	80	106	80	50	-	100	-

* Birds present, number unknown.

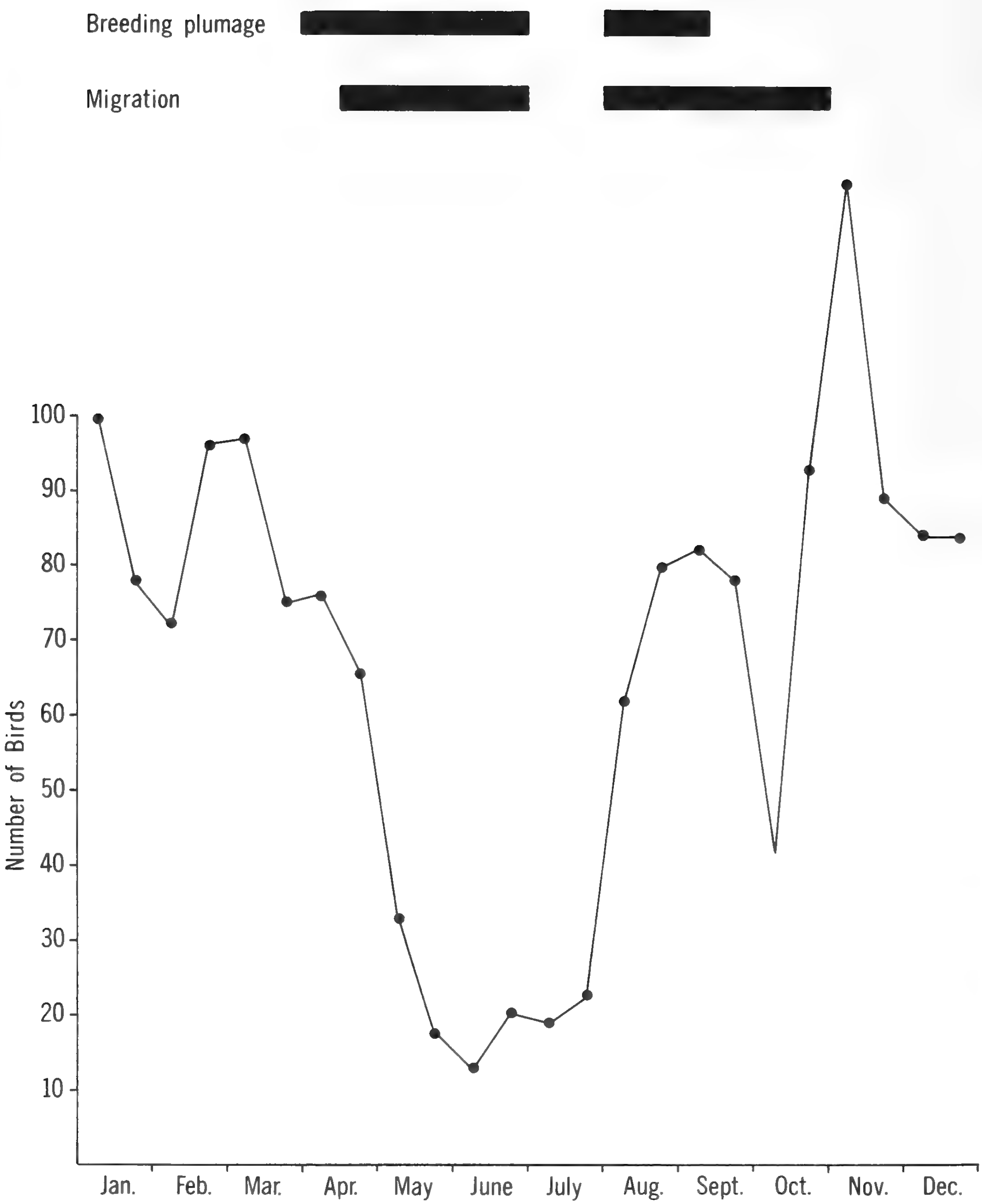

Figure RT-1. Annual cycle of Ruddy Turnstones on Green Island, Kure Atoll (based on semi-monthly estimates).

common only from August through April. Although exact data were lacking, this species apparently migrated from mid-April through June, and August through October.

Ecology

Ruddy Turnstones occurred commonly in open areas, both in the interior and along the beaches. Table RT-3 lists by season and location the percentage of turnstones seen on shorebird counts from 1963 to 1965. Turnstones were about equally abundant in the interior and along the beaches.

The main seasonal changes in distribution were a greater abundance of birds on the beaches and along the runway in fall, and a decrease in the numbers on the central plain during the summer, probably the result of the presence or absence, respectively, of migrants.

Ruddy Turnstones commonly occurred in pure flocks or with American Golden Plovers, and irregularly with Wandering Tattlers or Sanderlings. Unfortunately, numerical data on species association were not obtained.

Ruddy Turnstones occasionally were found under, or on top of, dense Scaevola. In 1966 Woodward noted turnstones feeding on oatmeal that was being used as rat bait.

Table RT-3. Percentage of Ruddy Turnstones recorded by season in different areas on Green Island, Kure Atoll, during 1963-65 shorebird counts.

Area	Winter	Spring	Summer	Fall
Ocean beach	15.5	15.4	16.5	11.8
Lagoon beach	16.0	19.2	27.9	20.3
North point	3.1	2.6	1.9	4.3
West point	14.5	7.2	5.6	10.1
Runway	9.2	8.6	9.7	22.9
Central plain	16.5	17.4	4.1	16.4
Rest of interior	25.1	29.6	34.3	14.2

Banding and Movements

The POBSP banded 24 Ruddy Turnstones and Robbins banded 7 (Table RT-4). One of these birds banded on 31 October 1963 was shot at the atoll on 29 August 1966, and another banded in November 1964 and recaptured on St. George, Pribilof Islands, Alaska, in August, 1967, was collected at Kure on 9 January 1969. In addition, one banded on 31 October 1963 was recaptured at Midway Atoll on 1 March 1966.

Four adult Ruddy Turnstones banded on St. George Island, Pribilof Islands, Alaska, in August 1966 were collected at Kure later that year.

Table RT-4. Ruddy Turnstones banded at Kure Atoll.

Year Banded	Number
1959	7
1963	4
1964	17
1965	1
1966	1
1967	1
Total	31

PINTAIL SNIPE *Capella stenura*

On 13 January 1964 King collected a male Pintail Snipe in the central plain. This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

COMMON SNIPE *Capella gallinago delicata*

Schreiber collected an immature male Common Snipe on 25 September 1966 in the south antenna field. A snipe, probably this bird, had been seen daily for the preceding five days in the same area.

This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

BRISTLE-THIGHED CURLEW *Numenius tahitiensis*

Status

Uncommon migrant, summer resident and winter resident. Populations ranged from 0 to 12. Recorded in all months, but may sometimes be absent in summer. Most common in fall.

Populations

Early observers recorded Bristle-thighed Curlews infrequently and in small numbers (Table BTC-1). POBSP estimates (Table BTC-2) were similar to earlier estimates, indicating total populations ranging from 0 to 12, and wintering populations of 1 to 5.

Annual Cycle

Bristle-thighed Curlews were usually present all year with peak numbers from September through at least February (Fig. BTC-1). In some years (*e.g.*, 1968) they were absent during the summer.

Table BTC-1. Previous records of Bristle-thighed Curlews on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Remarks and References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	several	(Wetmore, ms.).
1957	June 5	0	(Kenyon and Rice, 1958).
1959	October 3-8	6	(Robbins, 1966: 53).
1960	March 28	1	(Robbins, 1966: 53).
1961	January 19-21	6	(Robbins, 1966: 53).
	September 12-14	ca. 12	Loose groups on the beach; also fed on the open and low grassy areas of the island interior (Udvardy and Warner, 1964: 2).
1962	February 2-4	10	(Robbins, 1966: 53).
	August 6-8	1	(Robbins, 1966: 53).
1963	February 3-7	1	(Robbins, 1966: 53).

Limited data suggest migration periods from late July through at least October, and in April and May. Many of the curlews seen in the fall were present for only short periods. In September 1964, 9 Bristle-thighed Curlews were banded and tagged with orange streamers. By mid-October only 3 tagged birds were still present.

Ecology

Unlike the other shorebirds, Bristle-thighed Curlews occurred more frequently in the interior of the island than on the beaches. Only 13.8 percent of the curlews recorded on the 1963 to 1965 shorebird counts were seen on the beaches, while 48.6 percent were seen in the central plain, 15.7 percent on the runway, and 21.9 percent in other areas of the interior. This species usually occurred alone or in small intraspecific groups.

On three occasions, November 1963, November 1964, and December 1965, curlews were seen eating Polynesian rats.

Table BTC-2. POBSP semi-monthly estimates of Bristle-thighed Curlews on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	3	4	-	1	-	1
16-31	-	3	4	-	-	-	1
February							
1-15	-	*	6	9	1	-	1
16-28	-	2	6	-	-	-	3
March							
1-15	-	2	4	-	-	-	2
16-31	-	2	3	-	2	-	1
April							
1-15	-	2	4	-	-	-	2
16-30	-	2	1	2	-	-	0
May							
1-15	-	2	2	2	1	-	0
16-31	-	0	1	1	0	0	1
June							
1-15	-	0	1	1	0	0	1
16-30	-	0	1	1	0	4	-
July							
1-15	-	1	1	1	-	0	-
16-31	-	2	2	2	-	0	-
August							
1-15	-	2	2	1	-	0	-
16-31	-	2	-	1	-	3	-
September							
1-15	-	5	-	6	-	2	-
16-30	*	12	-	2	-	1	-
October							
1-15	*	4	-	-	-	0	-
16-31	*	5	-	-	-	0	-
November							
1-15	4	4	-	-	-	1	-
16-30	4	3	3	-	-	1	-
December							
1-15	4	4	1	-	-	1	-
16-31	3	5	-	1	-	1	-

*Birds present, number unknown.

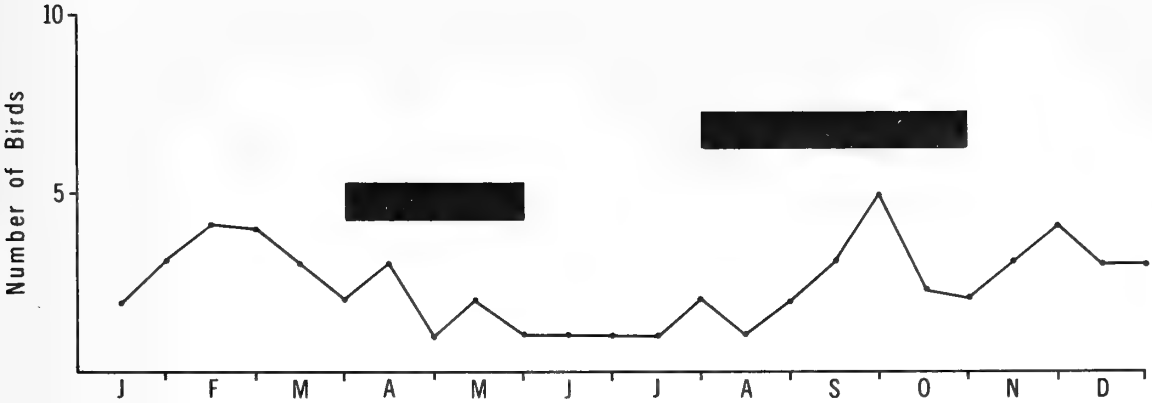

Figure BTC-1. Annual cycle of Bristle-thighed Curlews on Green Island, Kure Atoll (based on semi-monthly estimates; bars indicate migration periods.

Banding and Movements

Eleven Bristle-thighed Curlews were banded by the POBSP (9 in September 1963, 1 in October 1963, and 1 in January 1965) and 2 by Robbins in October 1959. An orange-streamered bird was seen at Midway Atoll on 7 December 1964 and 25 July 1965. These may have been different birds.

WOOD SANDPIPER *Tringa glareola*

Bratley collected a Wood Sandpiper of unknown sex in the north antenna field on the evening of 22 May 1965. On 15 May 1969 Kleen shot a male as it flew over *Scaevola* near the radar reflector. It had been seen earlier feeding on an albatross carcass along the southwest beach.

Wood Sandpipers have also been recorded in the Northwestern Hawaiian Islands at Midway Atoll (Clapp and Woodward, 1968).

WANDERING TATTLER *Heteroscelus incanum*

Status

Uncommon migrant, winter and summer resident. Populations ranging from 0 to 14. Recorded in all months, but sometimes absent in summer. Most common in fall and winter.

Populations

Wetmore in 1923 was the first biologist to record Wandering Tattlers on the atoll (Table WTa-1). Since that time the species has been recorded in small numbers by most visitors to the island.

Recent POBSP estimates (Table WTa-2) indicated populations of fewer than 15 Wandering Tattlers at any one time. These estimates did not vary significantly from the earlier ones.

Table WTa-1. Previous records of Wandering Tattlers on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Remarks and References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	ca. 2	(Wetmore, ms.).
1957	June 5	1	One emaciated individual caught along north beach (Kenyon and Rice, 1958: 190).
1959	October 3-8	4	(Robbins, 1966: 53).
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	4	(Robbins, 1966: 53).
	September 12-14	8-10	On beach (Udvardy and Warner, 1964: 2).
1962	February 2-4	15	(Robbins, 1966: 53).
	August 6-8	1	(Robbins, 1966: 53).
1963	February 3-7	10	(Robbins, 1966: 53).

Annual Cycle

Wandering Tattlers were recorded in all months, but in 1965 and 1968 they were absent in June or July. They were most common from mid-September through February of the succeeding year (Fig. WTa-1.)

Limited data suggested two periods of migration: one from late March to mid-June and another from mid-August through November.

Ecology

Tattlers were found mainly along the beaches and on the reef. The majority (57 percent) of those seen on the 1963 to 1965 shorebird counts

Table WTa-2. POBSP semi-monthly estimates of Wandering Tattlers on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	4	11	-	2	-	5
16-31	-	4	14	-	-	-	2
February							
1-15	-	*	1	7	1	-	2
16-28	-	3	10	-	-	-	2
March							
1-15	-	3	7	-	-	-	2
16-31	-	4	2	-	2	-	2
April							
1-15	-	2	6	-	-	-	2
16-30	-	2	0	5	-	-	2
May							
1-15	5	2	8	7	6	-	2
16-31	-	2	2	3	3	1	5
June							
1-15	-	4	2	3	3	6	3
16-30	-	1	0	2	0	4	*
July							
1-15	-	5	0	1	-	0	-
16-31	-	0	0	3	-	0	-
August							
1-15	-	3	1	1	-	0	-
16-31	-	4	-	2	-	2	-
September							
1-15	-	2	-	1	-	3	-
16-30	*	4	-	7	-	4	-
October							
1-15	*	9	-	-	-	5	-
16-31	*	6	-	-	-	5	-
November							
1-15	*	11	-	-	-	5	-
16-30	8	3	2	-	-	5	-
December							
1-15	8	5	2	-	-	5	-
16-31	4	1	-	2	-	5	-

*Birds present, number unknown.

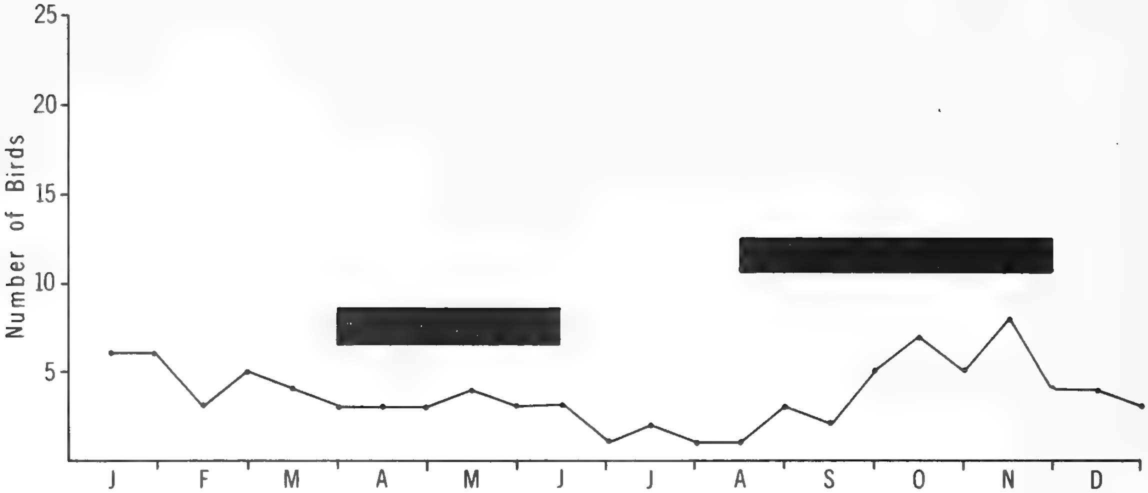

Figure WTa-1. Annual cycle of Wandering Tattlers on Green Island, Kure Atoll (based on semi-monthly estimates; bars indicate migration periods).

was along the rocky ocean beach. About 16 percent were seen along the lagoon beach, 15.3 percent at the west point, 7.2 percent at the north point, 3.1 percent along the runway, and 1.4 percent in the interior.

Usually Wandering Tattlers occurred singly or in twos, but occasionally they were found in small intraspecific or interspecific (with American Golden Plovers and Ruddy Turnstones) flocks.

Banding and Movements

One Wandering Tattler was banded in October 1959 and one in May 1969. No Tattlers banded on other islands were recorded at Kure.

LESSER YELLOWLEGS *Totanus flavipes*

On 30 August 1964 DuMont captured an immature female Lesser Yellowlegs in the central roost Sooty Tern colony. The bird was lying on the ground and was very emaciated. Other yellowleg observations of questionable validity were made on 28 September, and 9, 10, and 18 October 1963.

Lesser Yellowlegs have been recorded from Midway Atoll, Laysan, Maui, and Oahu in the Hawaiian Islands (Clapp and Woodward, 1968).

SHARP-TAILED SANDPIPER *Erolia acuminata*

Only two Sharp-tailed Sandpipers were collected: one on 7 October 1963 and one on 29 October 1963. In addition, four were banded: one on 30 October 1963, one on 31 October 1963, one on 2 November 1963, and one on 21 November 1963. Most of these birds were found in the open areas near the barracks.

Sharp-tailed Sandpipers have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll, Pearl and Hermes Reef, and Laysan (Clapp and Woodward, 1968).

PECTORAL SANDPIPER *Erolia melanotos*

Six Pectoral Sandpipers were collected: one on 14 October 1963, three on 25 September 1964, and two on 21 September 1966. In 1964 they were found along the runway with Ruddy Turnstones and in 1966 they were found on the tennis court.

Pectoral Sandpipers are regular visitors to the Hawaiian Islands and have also been recorded from Hawaii, Oahu, Midway Atoll (Clapp and Woodward, 1968) and Laysan (Ely and Clapp, ms.).

SHARP-TAILED or PECTORAL SANDPIPER *Erolia acuminata* or *melanótos*

Due to the difficulty of separating these two species in the field, only collected individuals were included in the respective species accounts. Other unidentified *Erolia* were recorded in late October 1963 (20), early November 1963 (3), 29 December 1963 (2), 14 January 1964 (2), 28 January 1964 (1), 5 February 1964 (1), 24 September 1964 (1), 26 September 1964 (1), 19 November 1965 (1), and 14 August 1966 (1).

DUNLIN *Erolia alpina sakhalina*

Lewis collected a female Dunlin on 15 November 1965 in the area just south of the barracks. On 28 May 1968 Woodward saw another Dunlin in full breeding plumage at the east end of the runway with two Ruddy Turnstones and three American Golden Plovers.

Dunlins have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll, Pearl and Hermes Reef, and Laysan (Clapp and Woodward, 1968).

LONG-BILLED DOWITCHER *Limnodromus scolopaceus*

On 3 October 1963 an immature male Long-billed Dowitcher was collected by Ludwig. Other dowitchers were noted on 4, 6, and 24 October 1968.

This is the only definite record of this species in the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

WESTERN SANDPIPER *Ereunetes mauri*

Huber collected a male Western Sandpiper on 30 December 1966. This bird was seen on both the lagoon and ocean beaches. It was always seen alone although Sanderlings were nearby.

This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

BAR-TAILED GODWIT *Limosa lapponica*

On 9 May 1966 Woodward saw two Bar-tailed Godwits roosting along the lagoon beach. One of these, a male molting into nuptial plumage, was subsequently collected.

Bar-tailed Godwits have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll, Lisianski and Laysan (Clapp and Woodward, 1968).

RUFF *Philomachus pugnax*

On 11 December 1963 Clapp saw a Ruff feeding with American Golden Plovers and Ruddy Turnstones in a rainwater puddle at the south end of the runway. A male, collected on the beach later in the day, had heavy fat deposits and was in winter plumage.

This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

SANDERLING *Crocethia alba*

Status

Uncommon spring and fall migrant, uncommon winter resident, and rare summer resident. Populations ranged from 0 to 13. Present from at least mid-August to mid-May of the succeeding year; in some years may also be found in the intervening period.

Populations

Sanderlings were first recorded from Kure Atoll by Wetmore in 1923 (Table Sand-1). Other early observers recorded this species infrequently and in small numbers. Recent POBSP estimates (Table Sand-2) were similar to these earlier estimates.

POBSP observations indicated that no more than 13 Sanderlings were present at any one time.

Table Sand-1. Previous records of Sanderlings on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Remarks and References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	4	(Wetmore, ms.).
1957	June 5	0	(Kenyon and Rice, 1958).
1958	May 9	1	(Rice, pers. corr.).
1959	October 3-8	1	(Robbins, 1966: 53).
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	2	(Robbins, 1966: 53).
	September 12-14	0	(Udvardy and Warner, 1964: 2).
1962	February 2-4	2	(Robbins, 1966: 53).
	August 6-8	0	(Robbins, 1966: 53).
1963	February 3-7	6	(Robbins, 1966: 53).

Annual Cycle

Sanderlings were present from at least mid-August to at least mid-May of the succeeding year, with peak populations from September through November (Fig. Sand-1). Occasionally they occurred in late May, June, July, and early August.

Limited data suggested two migration periods: one from March to mid-May and one from mid-August through November. The lack of a spring peak similar to the fall peak may indicate that spring migrants followed a different route than the fall migrants.

Ecology

Sanderlings occurred mainly on the sandy beaches, usually alone or in small intraspecific groups. They were infrequently seen along the runway with flocks of American Golden Plovers and Ruddy Turnstones.

The majority of Sanderlings (62.1 percent) seen on the shorebird counts of 1963 to 1965 was found along the lagoon beach. Other areas

Table Sand-2. POBSP semi-monthly estimates of Sanderlings on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	4	3	-	6	-	11
16-31	-	4	3	-	-	-	11
February							
1-15	-	*	1	7	4	-	9
16-28	-	5	4	-	-	-	6
March							
1-15	-	5	3	-	-	-	8
16-31	-	3	3	-	0	2	4
April							
1-15	-	1	2	-	-	-	9
16-30	-	1	0	3	-	-	6
May							
1-15	-	1	3	0	0	-	7
16-31	-	0	3	2	0	1	2
June							
1-15	-	0	1	0	0	1	0
16-30	-	0	0	0	0	1	0
July							
1-15	-	0	0	4	-	1	-
16-31	-	0	0	0	-	1	-
August							
1-15	-	0	0	1	-	*	-
16-31	-	2	-	2	-	1	-
September							
1-15	-	11	-	3	-	2	-
16-30	1	13	-	2	-	1	-
October							
1-15	*	12	-	-	-	*	-
16-31	*	9	-	-	-	*	-
November							
1-15	*	7	-	-	-	*	-
16-30	8	6	5	-	-	*	-
December							
1-15	8	2	0	-	-	*	-
16-31	5	2	-	6	-	10	-

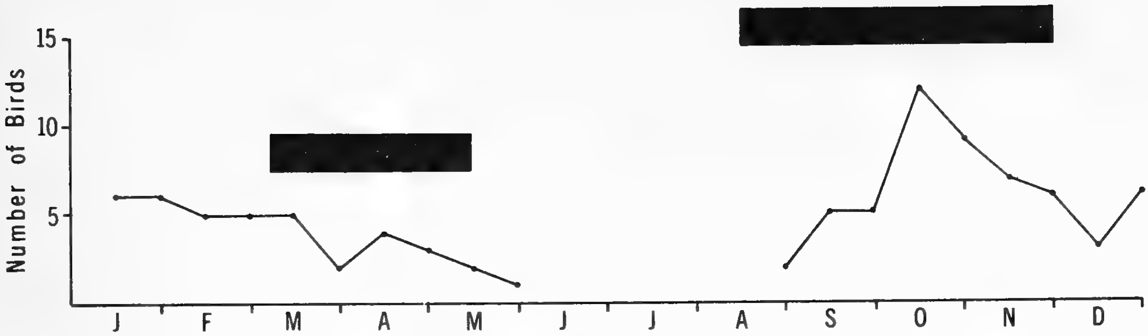

Figure Sand-1. Annual cycle of Sanderlings on Green Island, Kure Atoll (based on semi-monthly estimates; bars indicate migration periods).

where they occurred included the east or ocean beach (14.3 percent), the north point (14.3 percent), and the west point (9.3 percent). No seasonal differences in this distribution were noted.

Banding and Movements

No Sanderlings were banded by the POBSP nor were any found which had been previously banded.

RED PHALAROPE *Phalaropus fulicarius*

Fleet found a male winter-plumaged Red Phalarope with an injured wing on the beach near the east end of the runway on 13 March 1964. Another Red Phalarope in winter plumage was found dead in the north antenna field on 16 April 1969.

Red Phalaropes occur uncommonly at sea in the central Pacific and have been recorded in the Northwestern Hawaiian Islands from Pearl and Hermes Reef and Laysan (Clapp and Woodward, 1968).

RING-BILLED GULL *Larus delawarensis*

A female Ring-billed Gull in first nuptial plumage was found dead on 22 February 1963 by Coast Guard personnel and obtained by Sibley.

Ring-billed Gulls have been recorded from Pearl and Hermes Reef, Molokai, and Maui in the Hawaiian Islands (Clapp and Woodward, 1968).

HERRING GULL *Larus argentatus vegae*

Sibley collected three Herring Gulls in first winter plumage near the west point on 10 March 1963. Other specimens were collected on

10 November 1964, 20 January 1965, 8 March 1965, 1 April 1965, and 8 January 1969. Two of the latter were in first winter plumage; one was in furst nuptial plumage; and two were in second winter plumage. On 2 July 1968 Woodward found a well-bleached Herring Gull skull on the north point.

Herring Gulls are regular visitors to the Hawaiian Islands and have also been recorded from Midway Atoll, Pearl and Hermes Reef, Lisianski, Laysan, and Oahu (Clapp and Woodward, 1968).

SLATY-BACKED GULL *Larus schistisagus*

Fleet and Standen collected an adult male Slaty-backed Gull in winter plumage on 9 March 1965. This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

Robbins (1966) reported two "black-backed" gulls, possibly this species, 3-7 February 1963.

GLAUCOUS-WINGED GULL *Larus glaucescens*

On 10 March 1963 Sibley collected a Glaucous-winged Gull in first nuptial plumage near the west point. Prior to this the only records for the atoll were a mummy found on 18 April 1923 by Wetmore, and two seen 3 to 7 February 1963 by Robbins.

From 24 December 1964 until 9 March 1965 Glaucous-winged Gulls were commonly seen on the beaches of Green Island, mainly near the dump at the west point. An estimated 6 were present in late December, 7 in early January, 4 in late January, 2 in mid-February, and 3 in late February and early March. Five Glaucous-wings were collected as follows: 24 December 1964, 1 February 1965, 1 March 1965, 7 March 1965, and 9 March 1965. These specimens were all immature birds; 3 were in first nuptial plumage, 1 was molting into second winter plumage, and 1 was in second winter plumage. Two other individuals were banded in late December 1964. When captured, one of these gulls regurgitated a rat, while the other one regurgitated rat fur and crab chelipeds.

Three additional Glaucous-winged Gulls were collected: two on 31 December 1966 and one on 28 November 1968. One of the gulls collected in December was seen flying over and standing in the central plain. One of the December birds was in first nuptial plumage; only the wing of the other was found and it also appeared to be in nuptial plumage. The third bird was in second winter plumage.

Glaucous-winged Gulls have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll, Pearl and Hermes Reef, Lisianski, Laysan, French Frigate Shoals, and Necker (Clapp and Woodward, 1968).

GLAUCOUS GULL *Larus hyperboreus*

On 3 January 1965 Kepler saw a Glaucous Gull on the beach. One or two individuals were seen during the rest of the month and one, a male in first winter plumage, was collected on 17 January. This species occurred most frequently at the west point early and late in the day. One Glaucous Gull fed in the lagoon or on dead fish that washed up on the beach.

Wetmore found a beach-dried mummy on 18 April 1923.

This species has also been collected at Midway Atoll, Laysan, Kauai, Lanai, and Maui in the Hawaiian Islands (Clapp and Woodward, 1968).

BLACK-LEGGED KITTIWAKE *Rissa tridactyla*

On 24 December 1964 two adult and one immature Black-legged Kittiwakes were seen by Stadel and Kepler. One of the adults was seen for the last time two days later near the north point, and the immature, which was injured, was collected on 30 December.

Hackman saw another adult kittiwake flying along the edge of the reef on 28 March 1967. The next day he found the mummified remains of another adult along the edge of the runway.

Black-legged Kittiwakes have also been recorded in the Northwestern Hawaiian Islands from Pearl and Hermes Reef and Laysan (Clapp and Woodward, 1968).

BLACK TERN *Chlidonias niger*

On 20 June 1967 Woodward saw a Black Tern in breeding plumage flying north along the east beach. This constitutes the first record for the Northern Hawaiian Islands. They have been recorded on Oahu, and Maui in the Main Hawaiian Islands (Clapp and Pyle, 1968).

ARCTIC TERN *Sterna paradisea*

On 29 July 1968 Woodward found the mummified remains of an adult Arctic Tern along the southern edge of the runway. This was the first record of this species for the Northwestern Hawaiian Islands.

Arctic Terns are occasionally seen at sea in the central Pacific.

SOOTY TERN *Sterna fuscata*

Status

Abundant spring - summer breeder; 2,000 to 10,350 pairs annually. Present from late January or February through early November. Peak numbers from May through July. Breeding begins in late April or early May and continues through August.

Populations

Sooty Terns were recorded infrequently by early observers and prior to 1963 apparently did not breed on the island (Table ST-1). In that year an estimated 500 pairs nested at the northeast end of the runway. Since that time they have bred every year and the population appears to be increasing (Table ST-2).

Table ST-1. Previous records of Sooty Terns on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	0	(Wetmore, ms.).
1957	June 5	3	Flying over (Kenyon and Rice, 1958: 190).
1958	May 9	29	Flying over (Rice, pers. corr.).
1959	October 3-8	14	(Robbins, 1966: 53).
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	One found dead or injured (Udvardy and Warner, 1964: 3).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	50	No nests found (Robbins, 1966: 53).
1963	February 3-9	0	(Robbins, 1966: 53).

Table ST-2. POBSP semi-monthly estimates of Sooty Terns on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	0	-	0	-	1
16-31	-	0	5	-	-	-	0
February							
1-15	-	0	5	0	0	-	0
16-28	0	*	30	-	-	-	40
March							
1-15	-	*	100	-	-	-	2,000
16-31	-	*	1,000	-	750	150	2,000
April							
1-15	-	*	1,000	-	-	-	2,000
16-30	-	4,000	3,000	5,000	-	-	5,000
May							
1-15	50	4,000	6,000	10,000	17,000	-	25,000
16-31	-	4,000	8,000	16,000	17,000	15,000	25,000
June							
1-15	-	4,000	8,000	16,000	17,000	15,000	25,000
16-30	*	4,000	8,000	16,000	17,000	15,000	*
July							
1-15	-	6,000	6,000	16,000	17,000	15,000	-
16-31	-	6,000	5,000	15,000	-	5,000	-
August							
1-15	-	6,000	5,000	10,000	-	2,000	-
16-31	-	3,000	-	1,000	-	*	-
September							
1-15	-	200	-	-	-	*	-
16-30	*	*	-	-	-	*	-
October							
1-15	*	*	-	-	-	*	-
16-31	*	*	-	-	-	*	-
November							
1-15	*	*	-	-	-	0	-
16-30	0	0	0	-	-	0	-
December							
1-15	0	0	0	-	-	0	-
16-31	0	0	-	1	-	0	-

*Birds present, number unknown.

Available data indicate that Kure was colonized at least in part by Sooty Terns from Midway Atoll, 49 miles to the southeast. Thirty-six individuals banded on Midway from 1949 to 1962 were found breeding on Green Island 1964 to 1969. During POBSP studies large numbers of Sooties banded at Midway after 1963 were also found breeding (see Banding and Movements section). Undoubtedly the construction of the LORAN station created suitable habitat that was lacking earlier. Another factor of possible importance was the purposeful harassment of the Midway colony, especially in 1957 and 1958, to prevent Sooties from breeding near the runway on Sand Island. Perhaps many birds from Midway moved to Kure after being harassed but did not breed until enough adults were present and there was suitable habitat.

From 1966 to 1968 fairly accurate estimates of breeding populations were made by counting and marking all eggs found during the height of the breeding season. This method was believed to be at least 90 percent accurate. These counts indicated a population of 14,986 in 1966; 16,530 in 1967; and 5,700 in 1968. Table ST-3 breaks these counts down by colony:

Table ST-3. Populations of Sooty Terns breeding in the various colonies on Green Island, Kure Atoll, 1966-69.

Colony	1966	1967	1968	1969
Central roost	4,090	4,704	1,226	0
North roost	1,284	7,746	0	0
Northeast colony	9,612	4,100	0	0
South antenna field	0	0	4,474	20,700

Except for 1968, these counts were considerably higher than the earlier estimates of 4,000 in 1964 and 7,000 in 1965. Whether the size of the population actually increased or the higher counts were due to greater accuracy is not known. Assuming, however, that yearly egg and chick loss were fairly constant, it is unlikely that there was any significant change from 1964 to 1966, for in all three seasons an estimated 2,000 young fledged. In 1969 an estimated 20,700 individuals bred, but this estimate is not comparable to the more accurate counts.

In 1967 and 1968 the structure of the breeding population was determined by walking through the colonies with a string of 100 bands, capturing the first definitely breeding bird seen, banding it if unbanded, recording the band number if it was banded, and then capturing the next closest breeding birds until 100 birds were banded. From these data the percentage of the breeding population that was banded and the history of banded individuals were determined. In both years at least 25 percent of the population was handled and all areas in the colonies were covered, thus making it as representative a sample as possible. Table ST-4 compares the 1967 and 1968 data. (In 1968 all Sooties banded in 1967 were considered an unbanded birds.)

Table ST-4. Percentage of banded Sooty Terns in the breeding population on Green Island, Kure Atoll, 1967-68.

Banded	1967	1968
Interisland	18.6	12.8
1964*	22.3	19.9
1965*	5.3	5.4
1966*	53.8	61.9

* All banded as adults.

This analysis showed that the population structure was fairly consistent in both years and that the 65.6 percent decrease in 1968 was not the result of excessive adult mortality. Further support of this idea was provided by the rapid recovery in 1969 of the breeding population to the 1967 level. Unfortunately, the sampling of breeding birds in 1969 was insufficient to determine if this increase resulted from the influx of new birds; however, the structure of the population of banded birds remained relatively unchanged from the previous two years. Possibly a large segment of the 1967 population bred on other islands in 1968, probably Midway, or were present at Kure but did not breed. Sooty Terns which bred at Kure one year do breed on other islands as illustrated by two cases: one bird that bred on Kure in 1966 bred on Southeast Island, Pearl and Hermes Reef, in 1967; one that bred in 1967 at Kure bred in 1968 at Johnston Atoll.

From the 1967 data it can be calculated that no more than 50 percent of the Sooty Terns that bred in 1966 bred again at Kure the next year. In 1967, 5,876 breeding birds (35.9 percent of the total breeding population) were handled. Of these, 1,751 (29.8 percent) had already been banded: 390 at Kure in 1964, 92 in 1965, 943 in 1966; and 326 on other islands. Of the 1966 birds, 669 were breeding when banded. Extrapolating for the total breeding population of 1967, there were 4,926 (.298 x 16,530) previously banded birds, 1,882 (.382 x 4,926) of which were breeding in 1966. In 1966, 4,400 breeding Sooty Terns were banded. Therefore, in 1967 only a maximum of 42.8 percent of these birds was breeding at Kure, suggesting a large amount of turnover, especially when we consider that the population increased slightly. Whether these adults were present but did not breed, whether they bred on other islands such as Midway, or whether Sooty Terns do not breed every year was not determined.

The total number of Sooty Terns using the island at least once in 1967 was considerably larger than the maximum breeding population estimate of 20,700. With data collected from the breeding population samples, the total number of Sooty Terns using the island was calculated with the Lincoln Index as follows:

	1967	1968
Number of adults banded on Kure prior to year of recapture	12,544	16,720
Number of previously banded Sooties found breeding on Kure	1,425	627
Number of breeding birds captured	5,550	1,427
Percent of breeding populations that was banded at Kure	25.7	43.9
Total calculated population	48,809	38,087

These figures are not unreasonable as over 16,000 adult Sooty Terns have been banded, yet only 50 percent of the breeding population in 1968 had been previously banded.

Annual Cycle

Sooty Terns usually returned to the atoll in February. The birds heard 8 to 10 January 1969 were probably stragglers rather than returning migrants. Returning migrants were first heard over the island at night on 23 February 1964, 29 January 1965, and 17 February 1969, but it was not until 28 February 1964, 27 February 1965, and 25 February 1969 that they were first seen. At first only a few were present, but they increased in numbers until by the end of March hundreds were seen over the island during the day and considerably more heard at night. They were first seen on the ground in early March 1964, on 31 March 1965, and 27 March 1969. By the end of April thousands of adults were landing. During this early portion of the cycle the size of the population varied daily, depending in large part on weather conditions with few birds present on cool rainy days.

Shortly before egg laying began, large flocks of Sooties swirled over the potential breeding areas, landed, and courted. Eggs were laid shortly thereafter, but were soon deserted. In 1966 Sooties began laying eggs in six areas, but deserted all nests within a day after egg laying began before finally settling in a permanent area.

Usually egg laying began the first week of May, with a peak later that month; a few eggs were laid into late June. Peak periods of egg laying within the colony varied as much as three weeks between years (Table ST-5) and two weeks between the various subcolonies within one year (Table ST-6). Most eggs were laid within three weeks after the start of nesting, with a resultant sharply defined breeding cycle (Fig. ST-1).

Table ST-5. Major periods in the Sooty Tern breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964*	1965	1966	1967	1968	1969
Egg Laying	5 May-late May (?)	30 April-mid-June	6 May-mid-June	1 May-23 June	11 May-late June	*ca*. 25 April-late May
Peak Egg Laying	Late May (?)	6-17 May	15-25 May	1-21 May	3rd week May-1st week June	9-12 May
Hatching	June-July	4 June-mid-July	12 June-mid-July	28 May-?	10 June-3rd week July	25 May-at least late June
Peak Hatching	early July (?)	4-15 June	12-23 June	1-21 June	3rd week June-1st week July	mid-June
Fledging	August	late July-late August	9 August-3rd week August	?	4 August-late August	?

*Data accurate only in a general way.

Table ST-6. Peak egg laying periods in various Sooty Tern colonies on Green Island, Kure Atoll, 1966-69.

Colony	1966	1967	1968	1969
Central roost	15-22 May	2nd week May	3rd week May	-
North roost	15-17 May	3rd week May	-	-
Northeast colony	20-25 May	1st week May	-	-
South antenna field	-	-	Last week May-1st week June	9-12 May

Adult Sooties were extremely vociferous during the egg laying period but once incubation began were only rarely heard. At this time most of the birds in the colony were nesting.

Eggs hatched 26 to 31 days after laying ($\bar{x}$=28.1; n=30). Usually hatching began in early June and continued until the third week of July, with a peak one month later than the egg laying peak.

Adults were conspicuous during the hatching period, but within a week or so after most eggs had hatched, they were uncommon during the day.

In 1968 when most nests failed, swirls, similar to pre-breeding swirls, were present during the first three weeks of July.

Fledging began in late July and was completed by the end of August. Shortly after fledging young birds left the island. None returned for at least two years.

When the chicks fledged, the adults essentially disappeared and were seen only infrequently from September until early November, usually flying overhead. Except for a single December and three early January records, Sooty Terns were not seen from mid-November until late January or February. Their destination after they leave the atoll is unknown.

Nesting Success

Table ST-7 summarizes productivity of Sooty Terns from 1964 through 1968 on Green Island, Kure Atoll. The low rate of success in 1968 was due mainly to rat predation on eggs and young.

Hatching success was calculated for 80 eggs in 1965 as 53.5 percent, for 39 eggs in 1966 as 49.1 percent, and for 141 eggs in 1967 as 74.5 percent. The greater success in 1967 was due to the relative scarcity of Polynesian rats and the consequently reduced predation.

Ecology

Sooty Terns bred in several different areas on the island (Fig. ST-2 to 4). For convenience the colony areas were named central roost, north roost, south antenna field, and northeast colony (the area northeast of

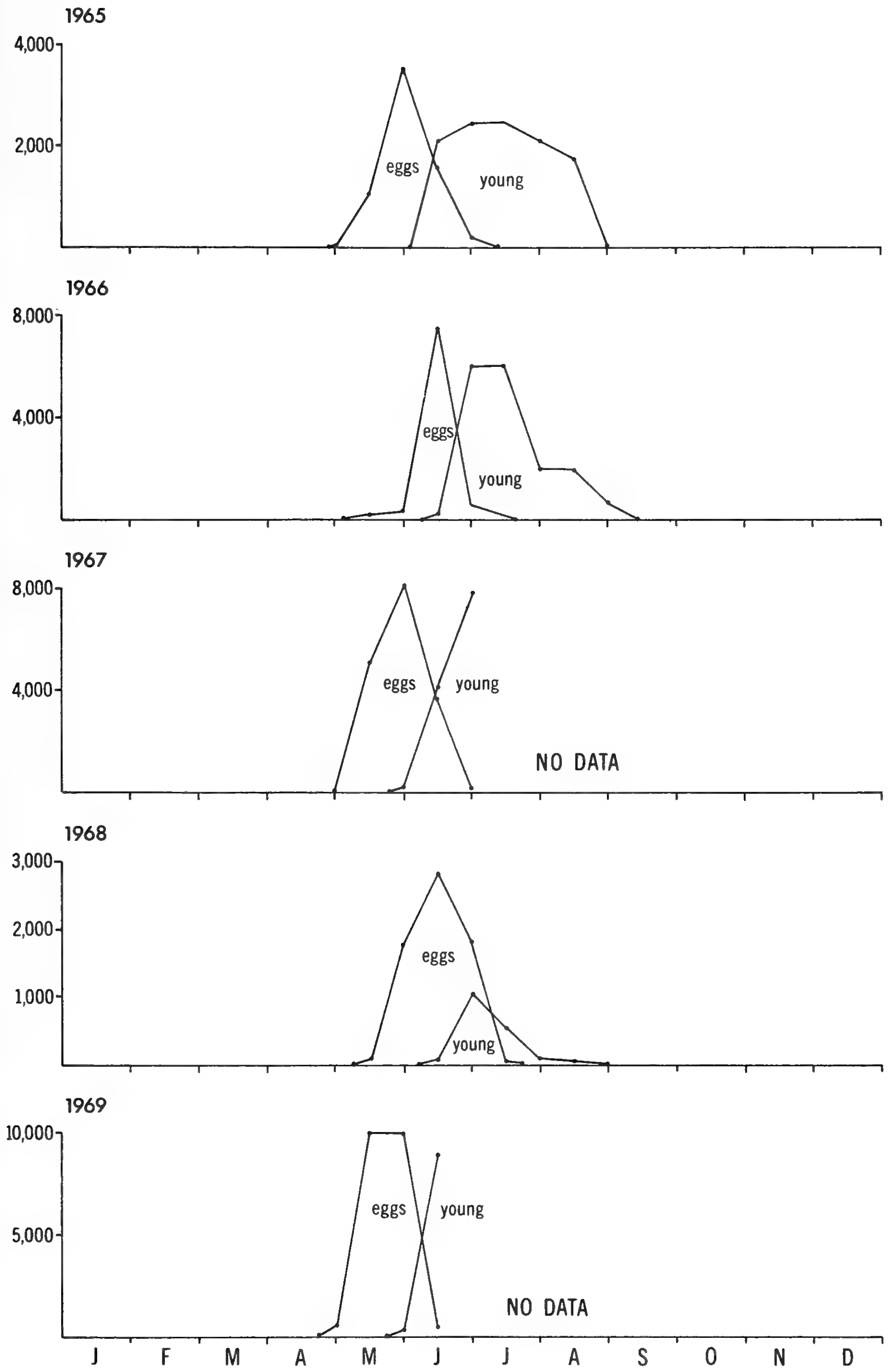

Figure ST-1. Breeding cycles of Sooty Terns on Green Island, Kure Atoll, 1965-69.

Table ST-7. Productivity of Sooty Terns on Green Island, Kure Atoll, 1964-68.

Year	Maximum Nest Count or Estimate	Estimate Number of Young Fledged	Percent Fledged
1964	2,000	2,000	--
1965	3,500	2,100	60.0
1966	7,493*	2,000	26.6
1967	8,265*	2,000	24.2
1968	2,850*	50	1.8

* Count.

the runway and east of the south antenna field). In 1964 Sooties bred solely in the central roost after they were chased from the runway. From 1965 through 1968 the colony divided into smaller units that generally did not breed in the same areas each year. Of the areas, the central roost was the only one utilized consistently from 1964 through 1968; it was deserted in 1969, possibly as a result of the spread of vegetation in that area. In 1969 Sooties bred only in the south antenna field. What factors control the selection of the breeding area is unknown, but Sooties swirled over several different areas before settling down.

Since 1963 some, or all (1964), of the birds in the colony have attempted to nest along the runway in the sand-Eragrostis association but have been chased away because of the potential danger to aircraft. If left unmolested, it is likely that they would breed there year after year.

At Kure, Sooty Terns bred in two major habitats--open areas of bare sand and scattered vegetation such as Eragrostis, Boerhavia, Tribulus, and Verbesina, and under Scaevola. Usually one egg was laid, but in some nests two eggs were found. In 1966 ten of 7,493 (0.13 percent) nests counted contained two eggs, while in 1968 eleven of 2,850 (0.39 percent) had two eggs. Whether the same female laid both eggs was unknown.

The egg was usually placed on bare sand but in a few cases was laid on top of matted vegetation, or, more rarely, in the midst of Eragrostis clumps. There was no evidence that adults modified the surroundings prior to egg laying. Rather, a slight depression was formed as incubation progressed. Although Sooties bred in open areas, most eggs were laid at the edge of some vegetation.

Egg densities were determined for six 100-square-foot plots in 1965, three in 1966, and six in 1967. In 1965 the number of eggs ranged from 4 to 22 ($\bar{x}$=13.3); in 1966 from 4 to 19 ($\bar{x}$=13.0); and in 1967 from 11 to 38 ($\bar{x}$=23.5).

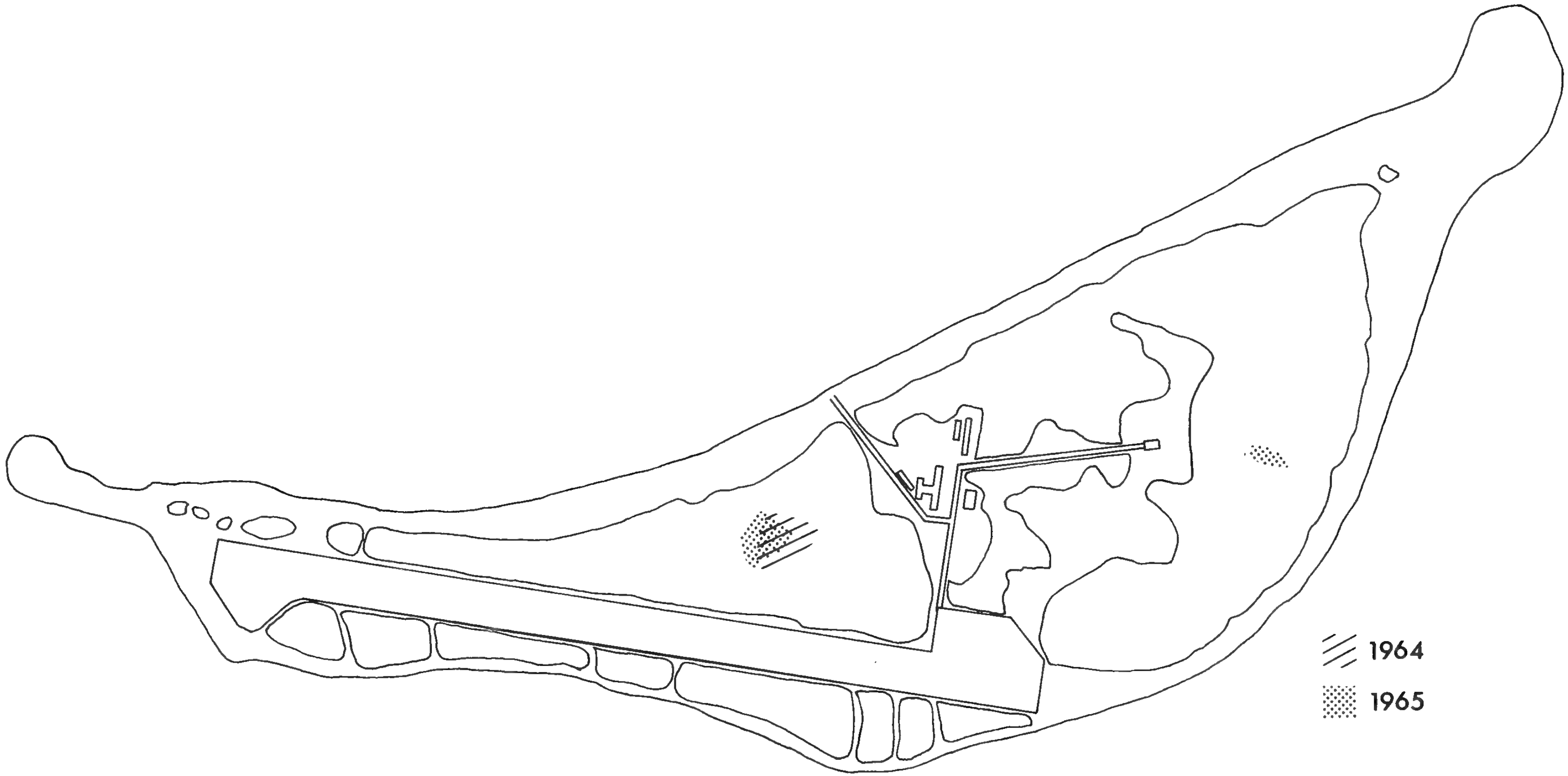

Figure ST-2. Distribution of Sooty Tern breeding areas on Green Island, Kure Atoll, 1964-65.

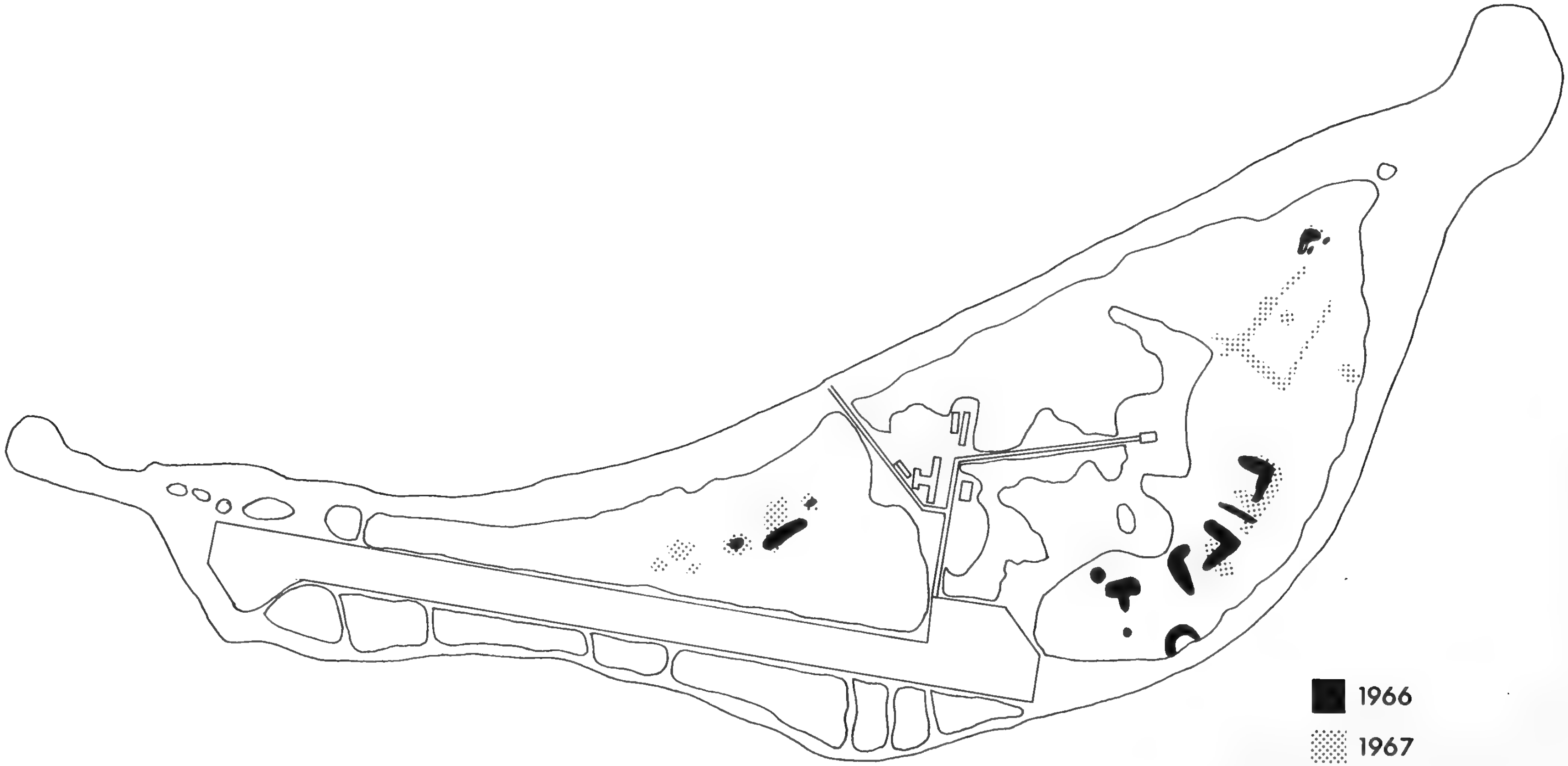

Figure ST-3. Distribution of Sooty Tern breeding areas on Green Island, Kure Atoll, 1966-67.

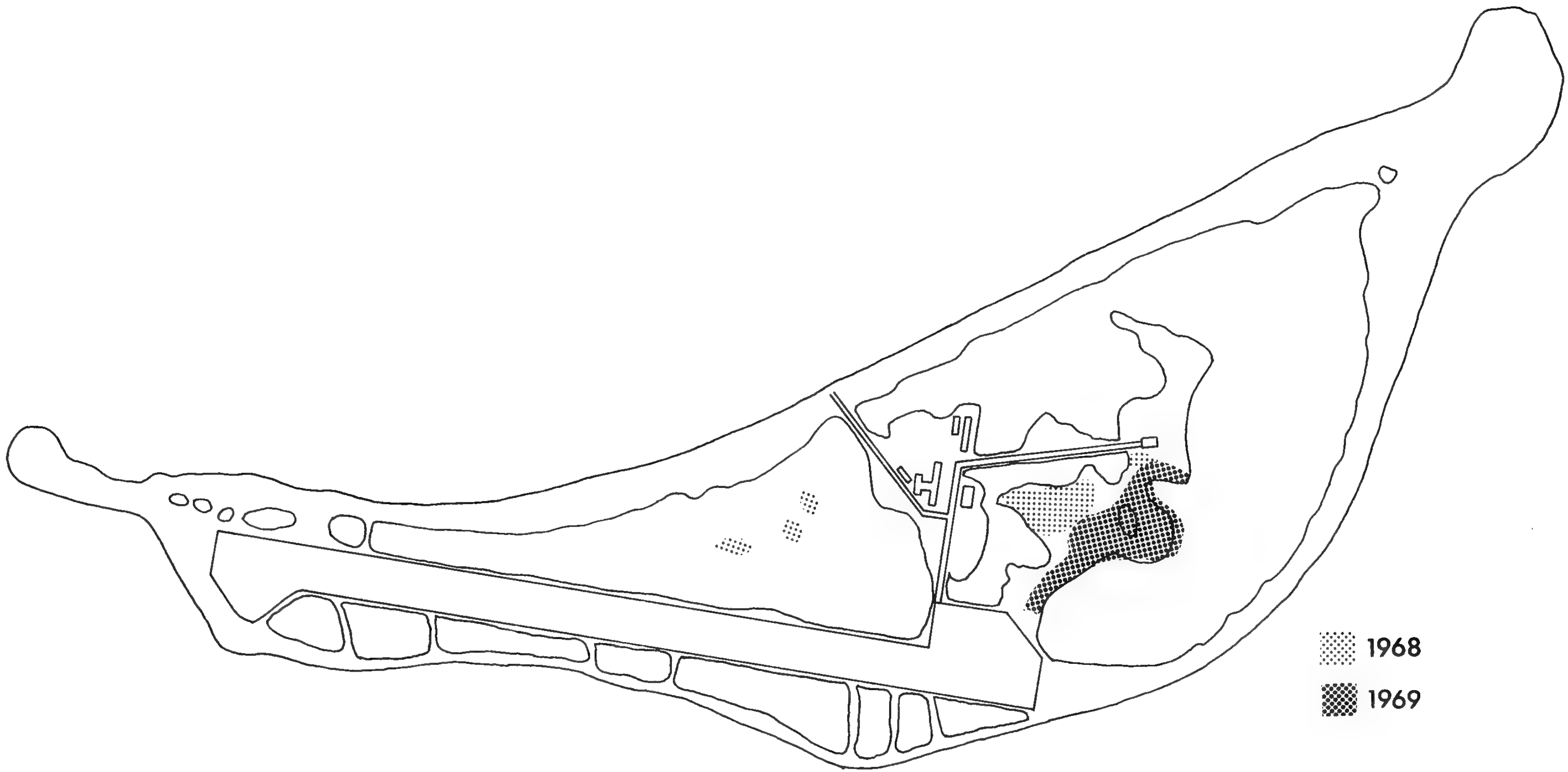

Figure ST-4. Distribution of Sooty Tern breeding areas on Green Island, Kure Atoll, 1968-69.

Non-breeding Sooty Terns roosted on the beaches and in the breeding colonies, or flew over the colonies. Although many Sooties were found roosting on the beaches prior to egg laying, no case of egg laying in these areas was known. In 1966 ca. 1,000 Sooty Terns roosted on the beach adjacent to the northeast colony for several days in late May.

Polynesian rats preyed heavily on Sooty Tern eggs and young. Yearly differences in hatching success were in large part attributable to the population size of these mammals.

Generally, Sooties did not breed in the same areas as the other tern species. In 1967 the Gray-backed Tern colony was engulfed by Sooty Terns in late May, but no detrimental effects were noted. However, in 1969 the Sooties apparently destroyed several Gray-back nests when the Sooties moved into the south antenna field.

Banding and Movements

The POBSP banded 18,534 adult Sooty Terns. Tables ST-8 and 9 summarize the recapture rates of these birds in subsequent years at Kure. As would be expected, breeding Sooties were recaptured more frequently than non-breeders. Although large numbers of adult Sooty Terns were usually handled each year (Table ST-10), these recapture figures are low, especially for the 1966 and 1967 breeders. Only in 1966 and 1967 were large numbers of breeders handled; in 1968 the breeding population was greatly reduced and in 1969 only a relatively few breeders were handled. Thus, the chances of recapturing a 1966 or 1967 banded bird were reduced.

Not all adult Sooty Terns banded at Kure were recaptured there. One hundred and forty-five of them were captured on other islands: 133 on Eastern Island, Midway Atoll; 5 on Southeast Island, Pearl and Hermes Reef; 2 on Laysan; 4 on Sand Island, Johnston Atoll; and 1 on Wilkes Island, Wake Atoll. All but four of these birds were banded as non-breeders. However, 105 were breeding on the island of recapture (100 at Midway Atoll, 4 at Pearl and Hermes, and 1 at Wake Atoll).

In addition, the POBSP banded as nestlings 5,569 Sooty Terns (1,601 in 1964; 1,600 in 1965; 1,800 in 1966; 500 in 1967; and 68 in 1968). However, an undetermined number banded in 1965 were actually adults since three of those banded as nestlings in 1965 were found breeding the next year. By June 1969 20 (1.3 percent) of the 1964 cohort had been recaptured at Kure (4 in 1966, 10 in 1968, and 6 in 1969). Eight of the 1965 cohort had also been captured (2 in 1968 and 6 in 1969), but it is possible that these birds were adults when banded. None of these Sooty Terns was found breeding.

Two Sooty Terns banded as nestlings were captured on Sand Island, Johnston Atoll: one banded on 24 July 1964 was found on 12 August 1967 and another banded on 26 July 1965 was captured on 30 August 1967.

Table ST-8. Recapture rates of adult Sooty Terns banded as breeders at Kure Atoll and recaptured there (expressed as percentages), 1965-69*.

Year Banded	n.	Year Recaptured 1965	1966	1967	1968	1969
1965	145	100.0	47.6 (28.9)	26.2 (16.6)	10.3 (6.9)	5.5 (5.5)
1966	4,400	--	100.0	22.7 (15.2)	9.3 (6.1)	3.6 (3.6)
1967	4,125	--	--	100.0	7.6 (4.3)	3.6 (3.6)
1968	800	--	--	--	100.0	2.9 (2.9)
1969	769	--	--	--	--	100.0

Table ST-9. Recapture rates of adult Sooty Terns banded as non-breeders at Kure Atoll and recaptured there (expressed as percentages), 1964-69*.

Year Banded	n.	Year Recaptured 1964	1965	1966	1967	1968	1969
1964	3,807	100.0	29.0 (2.9)	27.1 (15.8)	14.5 (10.6)	5.0 (3.2)	2.1 (2.1)
1965	468	--	100.0	40.4 (26.7)	22.2 (15.4)	8.1 (4.7)	3.6 (3.6)
1966	3,724	--	--	100.0	11.4 (8.0)	4.3 (2.7)	1.7 (1.7)
1967	51	--	--	--	100.0	2.0 (0.0)	2.0 (2.0)
1968	173	--	--	--	--	100.0	0.6 (0.6)
1969	72	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table ST-10. Number of adult Sooty Terns handled each year at Green Island, Kure Atoll, 1964-69.

	1964	1965	1966	1967	1968	1969
Breeding	0	181	5,022	5,890	1,510	1,277
Non-breeding	3,808	546	4,001	99	249	133
Totals	3,808	727	9,023	5,989	1,759	1,410

Movement to Kure Atoll of Sooty Terns banded on other islands was considerable. In four years of detailed breeding population study, 501 adult and 3 nestling Sooty Terns from other islands were found breeding at Kure. The majority (495) had been banded at Midway Atoll (36, including the 3 nestlings, prior to 1963) but there were also 3 from Laysan, 5 from Sand Island, Johnston Atoll, and 1 from Wilkes Island, Wake Atoll. At least 315 of the Midway-banded Sooties were recorded as breeding at the time of banding. How commonly this interchange of breeding birds occurs is unknown.

Besides the Sooty Terns found breeding, another 65 birds banded as adults and 6 banded as nestlings on other islands were also captured. Again the majority was from Midway Atoll (59), but there were also 2 from Southeast Island, Pearl and Hermes Reef, 1 from Laysan Island, and 9 from Sand Island, Johnston Atoll. The Sooty Terns banded as nestlings were from Midway (5) and Johnston Atoll (1). The lack of movement from French Frigate Shoals and the main Hawaiian Islands is surprising and at the moment unexplainable.

Two recorded movements involving Kure and the central Pacific equatorial islands are probably in error. On 11 May 1965 an adult with band number 793-59416, presumably a Phoenix Island bird, was recaptured at Kure. By changing the 59 to 95 it becomes at Kure band. Another band number 813-90913, can be changed to a Kure band by changing the 0 to a 1. Since these band numbers can be converted so easily to ones used on Kure, and since neither was verified by a specimen or noted as unusual at the time of capture, it is best to consider them highly questionable.

Although the number of Sooty Terns banded on other islands was large, when expressed as a percentage of the total number of birds banded, the amount of movement was relatively small. For example, 113,744 Sooty Terns were banded at Midway Atoll by the POBSP prior to 1967, yet only 517 (4.6 percent) were recaptured at Kure. On Laysan 117,311 Sooties were banded prior to 1968 and only 4 (0.003 percent) were found at Kure.

GRAY-BACKED TERN   Sterna lunata

Status

Uncommon spring-summer breeder; 20 to 39 pairs annually. Present from February or March until mid-September. Breeding begins in early April and continues to at least mid-August.

Populations

POBSP Gray-backed Tern population estimates (Table GBT-1) were larger than previous estimates (Table GBT-2), which is not surprising since these earlier trips were of short duration and only two, April 1923 and June 1957, occurred at the peak of the breeding cycle. However, the Gray-back population evidently changed little in size from 1923 when Wetmore, in late April, considered them "fairly common," a term applicable to recent POBSP April estimates.

Even POBSP data showed large differences in population estimates over a relatively short period. For example, in early July 1964 the maximum estimate was 4, but in late July 13 young Gray-backs were found which had been overlooked the previous two months.

POBSP estimates ranged from 50 to 100 Gray-backed Terns during the peak breeding periods. Most of these estimates were based on the number of birds seen in the breeding area and were, therefore, conservative. In 1967 and 1968 the most accurate data were obtained by finding a majority of the nests. Based on these nest counts, the breeding population in 1967 was 78, and in 1968 was 52. Since many nests were probably destroyed before observations began in 1968, the difference was probably not significant.

Earlier estimates actually agreed fairly closely with the accurate data, if nest losses were considered. For example, in 1964, 15 young Gray-backs were found in July and August. Based on Sooty Tern data, there was at least a 50 percent nest loss, so these nestlings represented 30 eggs at the beginning of the season, suggesting little or no change from 1964 to 1968.

Annual Cycle

In February of March, after an absence of at least four months, Gray-backed Terns returned to the atoll (earliest records: 6 February 1969 and 11 March 1964). Whether they were absent in February 1964 and 1965 or were merely overlooked is unknown. At first Gray-backs were present only at night, flying over the island or roosting on the beaches. By mid-March 1969, however, they were also present during the day.

Evidently the population arrived en masse rather than building up slowly. Maximum numbers of Gray-backed Terns were present from late

Table GBT-1. POBSP semi-monthly estimates of Gray-backed Terns on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	0	-	0	-	0
16-31	-	0	0	-	-	-	0
February							
1-15	-	0	0	0	0	-	20
16-28	0	0	0	-	-	-	50
March							
1-15	-	*	0	-	-	-	50
16-31	-	*	*	-	19	85	75
April							
1-15	-	*	50	-	-	-	75
16-30	-	*	50	75	-	-	50
May							
1-15	100	*	50	75	90	-	50
16-31	-	*	50	75	90	-	50
June							
1-15	-	*	50	75	90	75	45
16-30	*	*	50	75	90	85	*
July							
1-15	-	30	50	50	90	35	-
16-31	-	50	50	30	-	10	-
August							
1-15	-	75	50	50	-	5	-
16-31	-	10	-	*	-	0	-
September							
1-15	-	10	-	2	-	0	-
16-30	0	0	-	0	-	0	-
October							
1-15	0	0	-	-	-	0	-
16-31	0	0	-	-	-	0	-
November							
1-15	0	0	-	-	-	0	-
16-30	0	0	0	-	-	0	-
December							
1-15	0	0	0	-	-	0	-
16-31	0	0	-	0	-	0	-

*Birds present, number unknown.

Table GBT-2. Previous records of Gray-backed Terns on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	12	1 egg at the foot of bunch grass on bare ground (Munter, 1915: 137).
1923	April 17-22	fairly common	None nesting (Wetmore, ms.).
1957	June 5	8	Flying over (Kenyon and Rice, 1958: 190).
1958	May 9	1	Flying (Rice, pers. corr.).
1959	October 3-9	0	(Robbins, 1966: 53).
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	1 dead or injured bird (Udvardy and Warner, 1964: 3).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	40	20 nesting pairs (Robbins, 1966: 53).
1963	February 3-7	0	(Robbins, 1966: 53).

March to mid-August. Numbers decreased rapidly in late August and by mid-September Gray-backs had disappeared. In 1968, when no young fledged, the decrease occurred in mid-July.

Pre-breeding behavior was not recorded in detail, but the 1966 data were probably typical. During the last two weeks of April, Gray-backs were common throughout the day and night in open areas just north of the runway. At least one egg, which was later deserted, was laid under an Eragrostis clump. By early May they were not seen in these areas and, in fact, very few were seen at all. In late May the breeding colony was found under Scaevola in the north roost. While most Gray-backs shifted areas, one pair started breeding along the runway and another one along the northeast beach. This shifting of the colony from the open areas to the north roost accounted, in part, for the difficulty in 1964 in locating the colony.

Egg laying began one to two months after the birds returned. Munter found an egg on 28 March 1915, but there have been no recent egg dates

this early. The earliest POBSP egg records were 10 April 1965 and 9 April 1967 (with interpolated data). Egg laying continued through the third week of June.

Sufficient data were collected only in 1965, 1967, and 1968 to determine peak egg laying periods. In the former two years egg laying began in early April. In 1967 the peak of egg laying occurred the last two weeks of April, while in 1965 it was not until the last two weeks of June, at least for eggs that hatched. This suggests that the eggs laid in April 1965 were destroyed and the latter egg peak was due to renesting. In 1968 the peak occurred the last week of April, slightly later than the 1967 peak. Combined data show an egg laying peak from mid-April to mid-May (Fig. GBT-1).

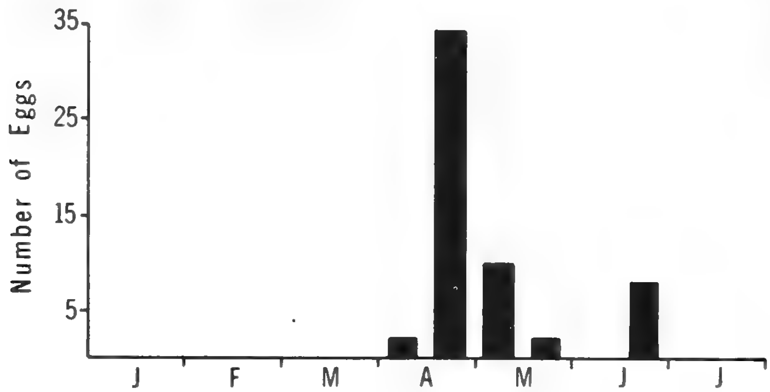

Figure GBT-1. Number of Gray-backed Tern eggs laid each semi-monthly period on Green Island, Kure Atoll, 1967-69.

Hatching began in mid-May (earliest record: 9 May 1967) and continued until the third week of July (latest record: 21 July 1968), with the peak about a month after the egg laying peak. Most eggs hatched by the end of June. The incubation period was unknown.

Fledging began as early as late June (1967) and was completed by the third week of August.

Figure GBT-2 shows the number of eggs and young present for each semi-monthly period where data were available. The most accurate data were for 1967 and 1968.

Nesting Success

Table GBT-3 shows the productivity of Gray-backed Terns from 1964 through 1969. The complete destruction of eggs and young in 1968 was probably the result of rat predation.

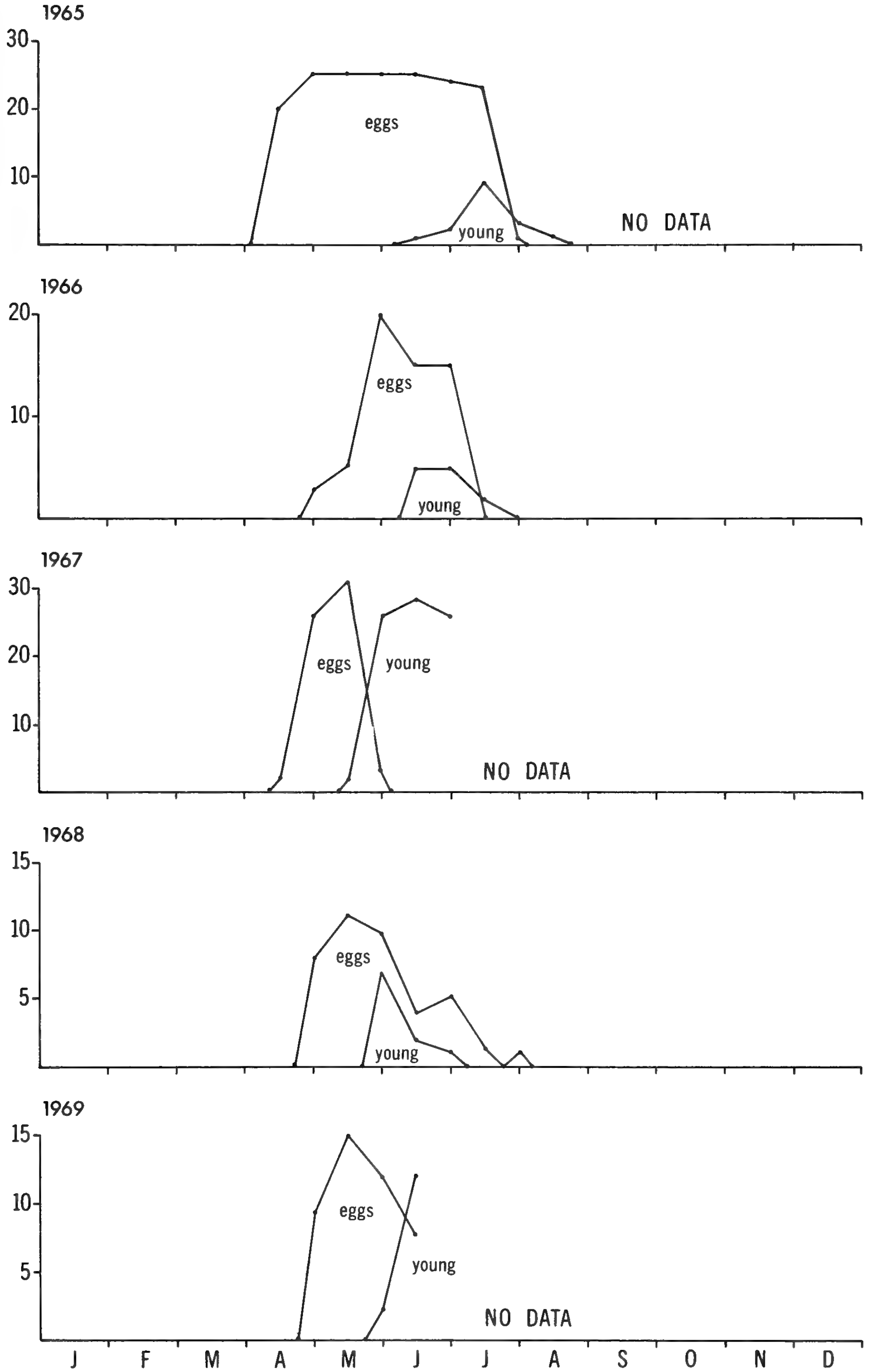

Figure GBT-2. Breeding cycles of Gray-backed Terns on Green Island, Kure Atoll, 1965-69.

Table GBT-3. Productivity of Gray-backed Terns on Green Island, Kure Atoll, 1964-69.

Year	Maximum Nest Count or Estimate	Maximum Egg Count or Estimate	Maximum Nestling Count or Estimate	Approximate Number Fledged	Percent Fledged	Number Banded
1964	25	0	25	25	--	15
1965	25	25	9	7	28.0	9
1966	20	20	5	2	10.0	0
1967	39	34	29	28	71.8	28
1968	26	19	10	0	0.0	9
1969	20	15	12	--	--	2

In 1967, 24 of 34 marked eggs (70.6 percent) hatched. The comparable figure for 1968 was 6 of 19 (31.6 percent). No fledging success rates were determined, mainly due to the difficulty of finding the young Gray-backs under the Scaevola.

Ecology

Gray-backed Terns generally bred in small colonies under Scaevola in the north roost (Fig. GBT-3). Only in 1964 and 1965 was the main colony in the same general area. Solitary nests were found under Scaevola along the runway and northeast beach in 1966, and near the south antenna field in 1969. Munter (1915) found an egg under a clump of Eragrostis; only one nest (1966), which was later deserted, has been found recently in a similar situation.

In 1967 there were 39 nests in ca. 4,365 square feet, or one nest per 112 square feet. The single egg was placed on gravel under Scaevola, generally near the base of the bush. Ten nests averaged 3.75 inches from the trunk of a Scaevola bush, and were under Scaevola of an average height of 32.2 inches. Although there was much vegetation on the ground in the area, none was present in the nests.

Non-breeding Gray-backed Terns roosted on the open beaches, mainly at the north point and other open areas in the north roost.

Many Gray-backs flew over the central plain catching moths on the wing. This was the only seabird species that caught food on the island.

Banding and Movements

The POBSP banded 50 adult Gray-backed Terns on Green Island, Kure Atoll, and Robbins banded 2 in August 1962. Table GBT-4 summarizes the recapture of these birds. None was found on other islands, nor were any Gray-backed Terns banded on other islands found at Kure.

Only one of the 63 nestlings banded was recaptured--one 1964 bird in 1969.

Table GBT-4. Recapture rates of adult Gray-backed Terns banded at Kure Atoll and recaptured there (expressed as percentages), 1962-69*.

Year Banded	n.	Year Recaptured 1962	1963	1964	1965	1966	1967	1968	1969
1962	2	100.0	50.0 (0.0)	50.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1964	15	--	--	100.0	20.0 (0.0)	20.0 (6.7)	13.3 (6.7)	6.7 (6.7)	0.0 (0.0)
1965	17	--	--	--	100.0	35.2 (11.8)	23.5 (23.5)	5.9 (5.9)	0.0 (0.0)
1966	4	--	--	--	--	100.0	25.0 (25.0)	0.0 (0.0)	0.0 (0.0)
1967	11	--	--	--	--	--	100.0	18.2 (18.2)	0.0 (0.0)
1968	1	--	--	--	--	--	--	100.0	0.0 (0.0)
1969	2	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

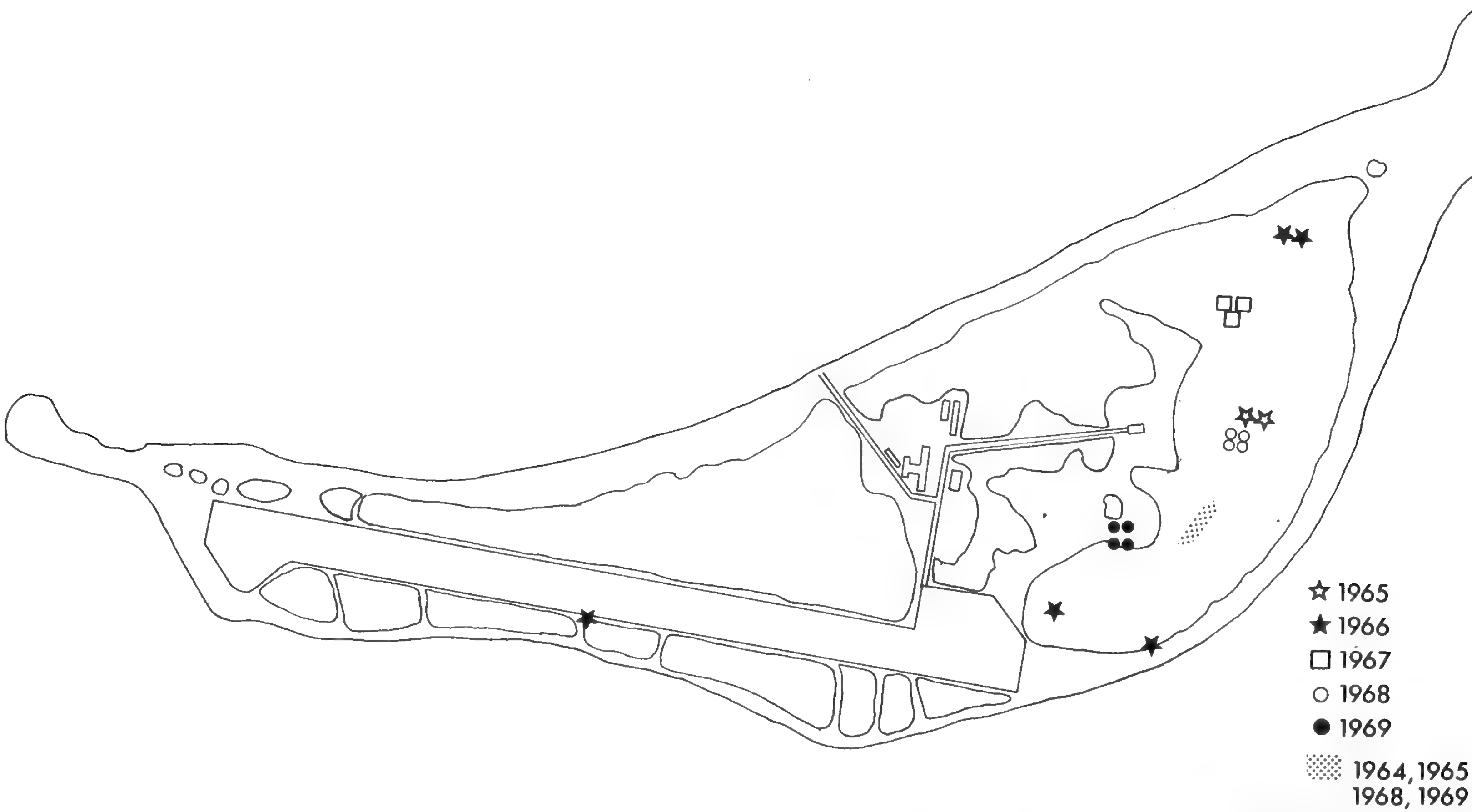

Figure GBT-3. Distribution of breeding Gray-backed Terns on Green Island, Kure Atoll, 1964-69.

BROWN NODDY *Anoüs stolidus*

Status

Abundant spring-summer breeder; 400 to 800 pairs annually. Present from March through December. Usually absent in January and February, although there were two records for January. Breeding from late April through early November with a peak in June and July.

Populations

Comparison of pre-POBSP Brown Noddy records (Table BN-1) with POBSP estimates (Table BN-2) indicate that this species increased in numbers after the construction of the LORAN station, which was not surprising because much of the area (mainly along the runway) now utilized by Brown Noddies was covered with dense *Scaevola* prior to 1961.

Brown Noddies were one of the easiest species to enumerate because of the conspicuousness of the birds and their nests. Recent POBSP estimates indicated a maximum population of 1,000 to 1,700 birds.

Table BN-1. Previous records of Brown Noddies on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	?	(Wetmore, ms.).
1957	June 5	252	66 eggs found (Kenyon and Rice, 1958: 190).
1958	May 9	70	(Rice, pers. corr.).
1959	October 3-8	500	Nesting (Robbins, 1966: 53).
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	?	(Udvardy, 1961: 46).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	200	75 nests (Robbins, 1966: 53).
1963	February 3-7	1	(Robbins, 1966: 53).

Table BN-2. POBSP semi-monthly estimates of Brown Noddies on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	3	-	*	-	0
16-31	-	0	150	-	-	-	0
February							
1-15	-	0	0	0	0	-	0
16-28	0	0	0	-	-	-	0
March							
1-15	-	0	2	-	-	-	0
16-31	-	55	400	-	0	0	200
April							
1-15	-	250	400	-	-	-	400
16-30	-	750	500	500	-	-	400
May							
1-15	500	750	700	600	1,650	-	400
16-31	-	750	900	700	1,650	500	400
June							
1-15	-	750	1,100	900	1,650	1,000	450
16-30	*	750	1,350	900	1,650	1,200	*
July							
1-15	-	600	900	900	1,650	1,200	-
16-31	-	1,000	750	900	-	1,200	-
August							
1-15	-	1,000	750	800	-	1,200	-
16-31	-	1,000	-	700	-	800	-
September							
1-15	-	800	-	400	-	800	-
16-30	*	500	-	400	-	600	-
October							
1-15	*	400	-	-	-	*	-
16-31	*	250	-	-	-	300	-
November							
1-15	400	150	-	-	-	300	-
16-30	75	75	100	-	-	*	-
December							
1-15	75	50	20	-	-	4	-
16-31	0	14	-	*	-	0	-

*Birds present, number unknown.

In 1965, 1967, and 1968 population estimates were based on counts of adults and nests (Table BN-3). These data suggest that the total population changed only slightly from year to year. However, the number of noddies breeding each year varied--1,000 in 1964, 1,056 in 1965, 802 in 1966, 1,568 in 1967, and 978 in 1968. The reason for these fluctuations are unknown. No counts were made in 1969 so it is impossible to determine if the apparent decrease that year was real.

Table BN-3. Comparison of Brown Noddy counts on Green Island, Kure Atoll, for 1965, 1967, and 1968.

Date of Count	1965	1967	1968
March 14	2	--	--
21	1	--	--
27	1	--	--
April 3	99	--	--
10	135	--	--
18	365	--	--
24	336	--	--
May 1	428	--	--
8	594	739	--
15	573	624	--
22	655	627	--
29	770	681	--
June 5	914	--	--
6	--	760	--
8	--	--	367
12	784	--	--
14	--	858	552
22	--	--	564
26	869	--	--
29	--	--	713
July 6	--	--	719
10	441	--	--
13	--	--	614
22	--	--	645
24	490	--	--
29	--	--	730
August 13	616	--	--

Annual Cycle

Brown Noddies were generally absent from mid-December until the last two weeks in March (earliest records: 30 March 1964, 14 March 1965, and 19 March 1969). Following an initial appearance on the sand-spits west of Green Island (in 1969 they were first seen at the north end of the island), they invaded the southern beaches of Green Island, moving gradually northward and encircling the entire island; then they started flying over the interior. By mid-April they occupied all of their breeding areas. Peak Brown Noddy populations were present from May through August.

Courtship was first observed on 9 April in 1964 and 6 April in 1965, but it was not until May in both years that eggs were laid. Although the first eggs were laid at approximately the same time each breeding season, yearly differences in breeding peaks existed (Table BN-4). For example, in 1967, 512 nests were present in late May, while one year later only 30 were found in that month. Figure BN-1 shows the number of eggs and young present each semi-monthly period for which there are data.

Egg laying began as early as late April (1967) and some eggs were laid as late as late August. Most egg laying, however, was completed by mid-July. Usually there was an extended period of egg laying, with numerous eggs laid one to two months after the start of breeding, which resulted in a broad egg peak. However, in 1968 most eggs were laid during a three-week period. Figure BN-2 compares the number of first eggs laid each week at the north point in 1967 and 1968. The 1968 pattern may be explained in part by the lateness of the breeding cycle. POBSP data showed that peak periods of egg laying in this species occurred no later than early July. Therefore, if breeding was delayed, most noddies would reach breeding condition at the same time, with a resultant sharp egg laying peak as in 1968.

Usually only one egg was laid in a nest, but in 1968 two of 89 nests (2.2 percent) at the north point contained two eggs. Neither nest produced young.

On Kure eggs hatched 34 to 40 days after laying ($\bar{x}$=36.1, n=76). Eggs hatched from late May until late September. Hatching peaks occurred from the last two weeks of June through July and showed the same yearly variations as the egg laying peaks.

On the average the young birds began to fly 46.5 days after hatching (n=66, range 40-56). Fledging, therefore, began in late July and continued until at least early November. Most young began flying in August and September. After they left at the end of the breeding season, young Brown Noddies did not return to Kure for at least two years.

Table BN-4. Major periods in the Brown Noddy breeding cycle on Green Island, Kure Atoll, 1964-69.

Period	1964	1965	1966	1967	1968	1969
Egg Laying	13 May-late August	8 May-at least early August	12 May-late July	late April-at least part of June	18 May-early September	7 May-?
Peak Egg Laying	June	last week May-mid-June	first 2 weeks June	May	last 2 weeks June-1st week July	?
Hatching	27 June-26 September	12 June-?	30 June-late August	30 May-?	22 June-late August	?
Peak Hatching	late July-?	late June-late July	first 2 weeks July	last 2 weeks June	last week July	?
Fledging	mid-July-mid-November	late July-?	early August-?	mid-July-?	first week August-early October	?

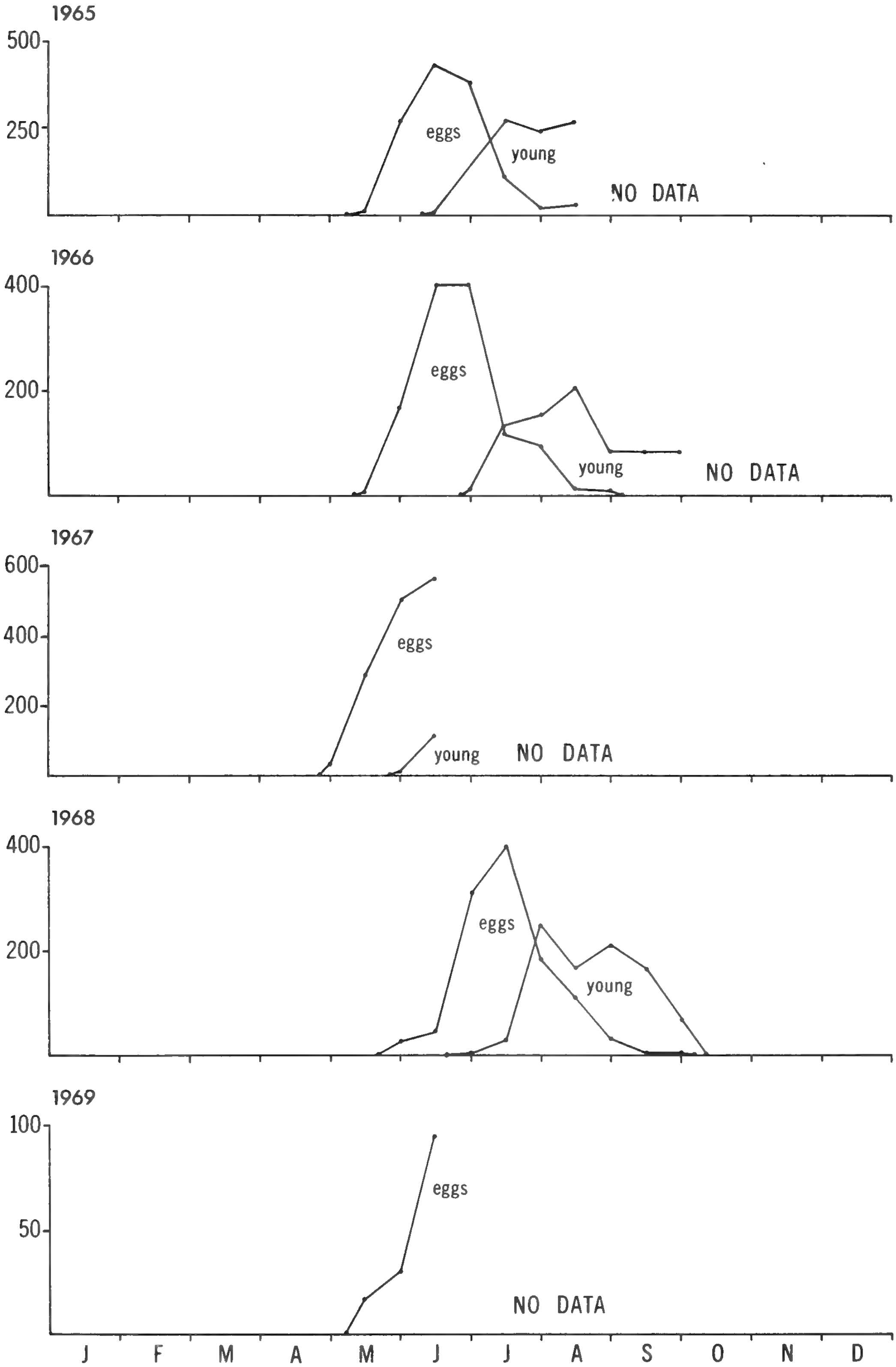

Figure BN-1. Breeding cycles of Brown Noddies on Green Island, Kure Atoll, 1965-69.

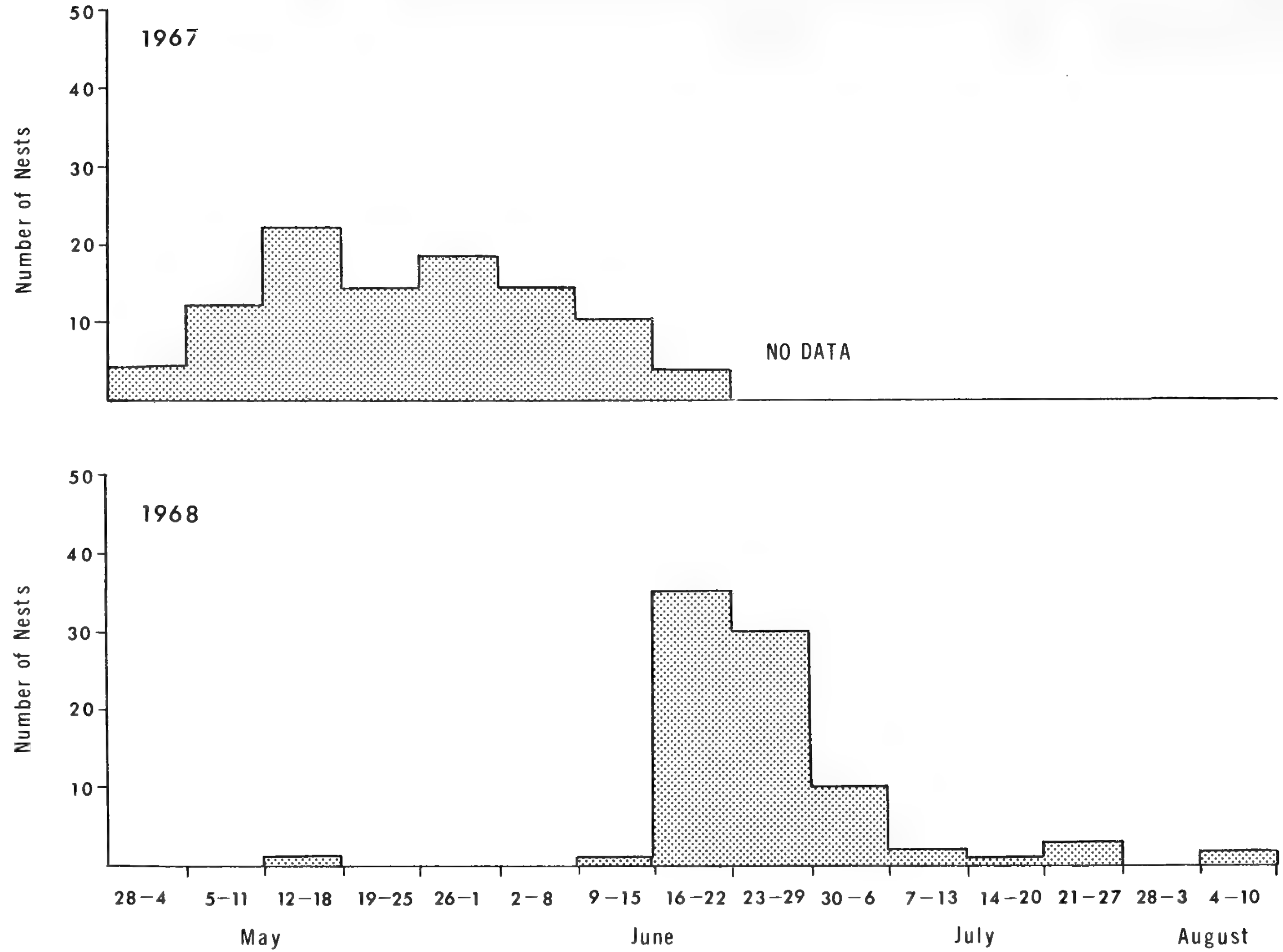

Figure BN-2. Number of Brown Noddy eggs laid each week at north point study area on Green Island, Kure Atoll, 1967-68.

Nesting Success

Detailed nesting success data for Brown Noddies were collected at the north point in 1967 and 1968. In the former year, 26 of 33 eggs (78.8 percent) that should have hatched by 20 June did so. Comparable figures for 1968 showed that 59 of 93 eggs (63.4 percent), or 59 of 89 nests (66.3 percent), hatched. Young fledged in 1968 from 38 of the 89 nests (42.7 percent), representing 64.4 percent of the young that hatched.

Table BN-5 summarizes productivity of Brown Noddies from 1964 through 1968.

Table BN-5. Productivity of Brown Noddies on Green Island, Kure Atoll, 1964-68.

Year	Maximum Nest Count or Estimate	Approximate Number of Young Fledged	Percent Fledged
1964	500	250	50.0
1965	528	260	49.2
1966	400	187	46.8
1967	784	450	57.4
1968	489	210	42.9

Ecology

Brown Noddies bred in most major habitats on the island, from open beaches to dense *Scaevola* thickets. Figure BN-3 shows the general location of the 1967 breeding areas. This was a typical pattern for all years. Although they bred over a considerable portion of the island, they avoided several areas such as the central plain and northeast beach.

Only 13.5 percent of the nests were located in the midst of *Scaevola*, The majority, 33.8 percent, was located along the lagoon beach at the beach-*Scaevola* ecotone. Lesser concentrations were found along the western edge of the runway (15.8 percent), the west end of the runway (10.2 percent), and the north point (13.4 percent). A similar distribution pattern was noted in 1968.

Nest construction of Brown Noddies was as variable as their nest sites. Four general types of nest were found, varying in location and the amount of vegetation. Most nests were on the ground--some with no vegetation added (Type I), some with a little vegetation (Type II), some with large amounts of vegetation (Type III), and some bulky nests were built in *Scaevola* (Type IV). In 1967 all nests found were classified according to the preceding types with the following results: Type I - 208 (30.4 percent), Type II - 410 (59.8 percent), Type III - 26 (3.8 percent), and Type IV - 41 (6.0 percent).

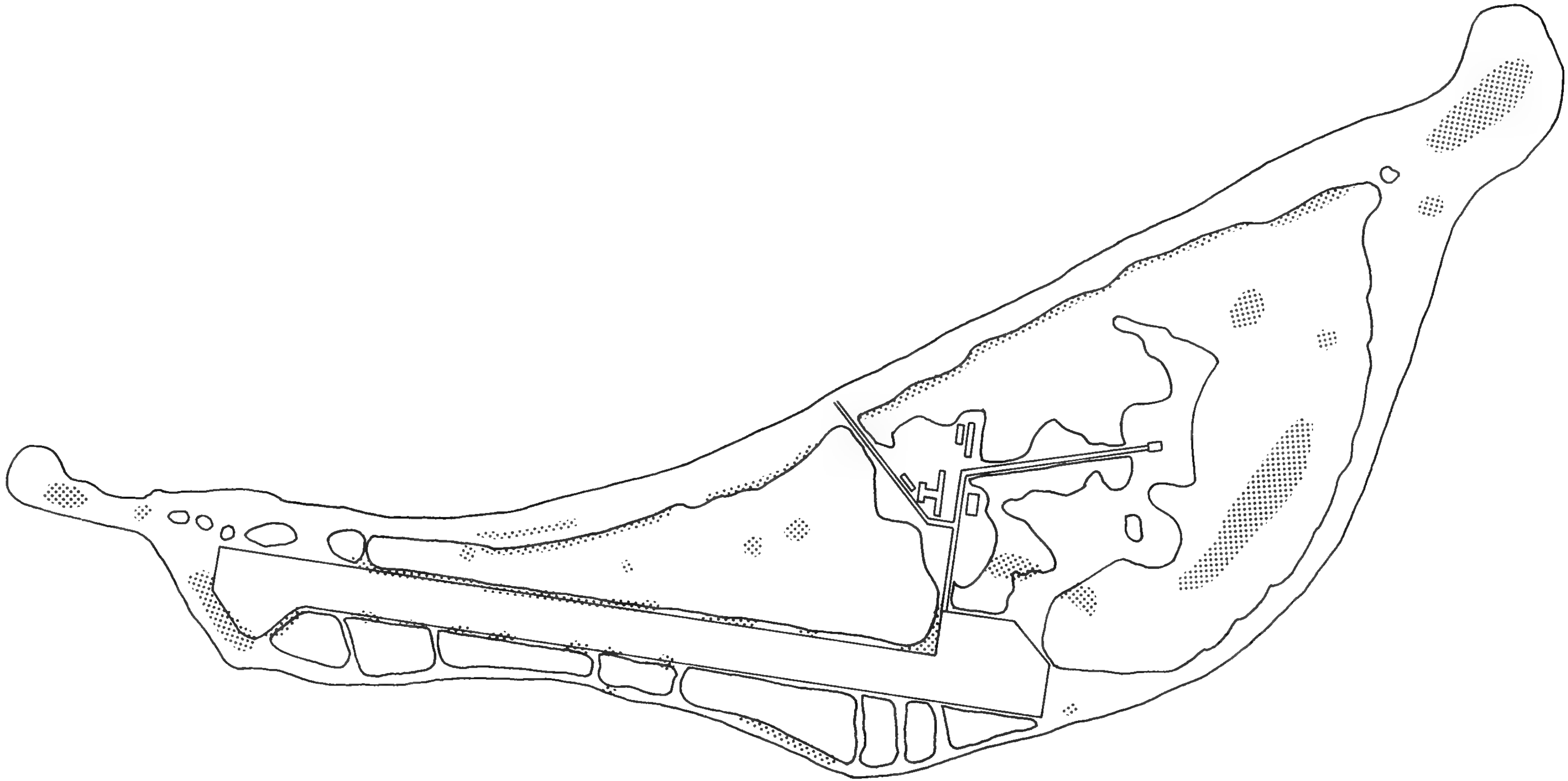

Figure BN-3. Distribution of breeding Brown Noddies on Green Island, Kure Atoll, 1967.

Scaevola, Eragrostis, Boerhavia, Ipomoea, and algae were the main types of vegetation present in the nests. Many nests also contained sea urchin shells, ropes, crayons, and/or other debris.

During the day Brown Noddies commonly roosted on the beaches and on coral blocks in the water. At night they roosted on Scaevola, mainly along the lagoon beach. Some noddies were also found on man-made structures such as the radar reflector.

In the summer of 1965 many young Brown Noddies were found with open wounds in the body cavity, just ahead of, or behind, the wings--a typical sign of Polynesian rat predation. Rats were also observed eating noddy eggs.

It is well known that downy Brown Noddies are polymorphic, varying mainly in the color of body down. Usually the color information given is the proportion of dark and light birds in the population. However, considerably more variation than has been recorded in the literature was found at Kure.

Basically downy Brown Noddies vary in three characters: (1) amount of white on the head, (2) color of the abdomen, and (3) color of the rest of the body down. The following six classifications were used for the amount of white on the forehead: (1) none, (2) lore white, (3) forehead white, (4) one-half of head white (area from bill to just above the eyes), (5) top of head white (to posterior portion of skull), and (6) whole head white (extending down neck). The abdomen may be: (1) white, (2) the same color as the rest of the bird (dark), or (3) somewhat lighter than the rest of the body but not white (light). The rest of the body down may be (1) white, (2) medium gray, (3) deep gray, or (4) black. Some individuals may also have combinations of these colors such as white down with gray edgings, or medium gray down with white edgings.

Using these classifications, the plumage of 265 downy Brown Noddies was described in 1968 (Table BN-6). The color of the body down is considered to be the major category in this table. Light-phase birds, especially ones with medium gray body down, predominated. However, when using all three characters, those with white body down and gray edgings were most abundant. Percentages of the various color phases found in 1968 were similar to those found in 1967.

Two individuals were unique. One had white body down with gray edgings and a black line which curved forward along the side of the head to the mandible. The other had a black back and collar while the rest of the down was white with gray edgings.

In 1968 fledging success was determined for all basic color phases at the north point (Table BN-7). These limited data indicate that there may be differential mortality of the various morphs. More work is necessary to determine if these differences exist every year and what the exact causes of death are and their possible correlation with down color.

Table BN-6. Percentages of various Brown Noddy color phases on Green Island, Kure Atoll, 1968.

Plumage Description		Number Recorded	Percent of Sample
I. White Body Down	Subtotal	76	28.7
White body down			
Head and abdomen white		4	1.5
White body down with gray edgings		72	27.2
II. Medium Gray Body Down	Subtotal	101	38.2
Gray body down			
Forehead white, abdomen white		3	1.1
Forehead white, abdomen light		2	0.8
1/2 of head white, abdomen white		18	6.8
1/2 of head white, abdomen light		3	1.1
Top of head white, abdomen white		22	8.3
Top of head white, abdomen light		6	2.3
Head white, abdomen white		41	15.5
Head white, abdomen light		2	0.8
Gray body down with white edgings		4	1.5
III. Deep Gray Body Down	Subtotal	80	30.2
Lore white, abdomen white		6	2.3
Lore white, abdomen light		9	3.4
Forehead white, abdomen white		7	2.6
Forehead white, abdomen light		12	4.5
1/2 of head white, abdomen white		14	5.3
1/2 of head white, abdomen light		17	6.4
Top of head white, abdomen white		4	1.5
Top of head white, abdomen light		6	2.3
Head white, abdomen white		2	0.8
Head white, abdomen light		3	1.1
IV. Black Body Down	Subtotal	8	3.1
Dark head, abdomen light		1	0.4
Lore white, abdomen light		3	1.1
Forehead white, abdomen white		2	0.8
Forehead white, abdomen light		2	0.8
	Total	265	ca. 100.0

Table BN-7. Nesting success of the four basic color phases of Brown Noddies on Green Island, Kure Atoll, 1968.

	Color Phase: White	Gray	Deep Gray	Black
Number hatched	17	24	11	5
Number fledged	10	14	9	4
% fledged	58.8	58.3	81.8	80.0

Banding and Movements

Robbins banded 72 adult Brown Noddies and the POBSP banded 493. Table BN-8 summarizes the recapture of these birds at Kure in subsequent years. Since little effort was expended catching this species, these recapture rates are low. One adult Brown Noddy banded on 5 May 1964 was captured on Eastern Island, Midway Atoll, on 19 July 1965.

One thousand two hundred and thirty-three nestling Brown Noddies were banded at Kure Atoll (3 in 1959, 53 in 1962, 1 in 1963, 173 in 1964, 212 in 1965, 199 in 1966, 91 in 1967, and 501 in 1968). Six of the 1962 cohort were recaptured (2 in 1964, 1 in 1965, 3 in 1966 including one previously captured in 1964, and one in 1969); 6 of the 1964 cohort in 1969; and 1 of the 1965 cohort (in 1967). In addition, 3 of the 1964 cohort were found on other islands: one on Eastern Island, Midway Atoll, in 1966; one on Lisianski in 1967; and one at Babelthuap, Palau Island, Caroline Islands, some 2,900 nautical miles away, on 21 May 1965.

Two nestling Brown Noddies banded on Eastern Island, Midway Atoll, in 1962 by Robbins were recaptured at Kure Atoll, one in 1966 and the other in 1969.

BLACK NODDY — *Anoüs tenuirostris*

Status

Abundant visitor with peak populations present from May through September; maximum estimate 2,000. Recorded in all months but generally absent from late December through mid-March.

Populations

Since the number of Black Noddies varied considerably each day and throughout the year, it was difficult to determine if the difference between earlier estimates (Table BlN-1) and recent POBSP estimates (Table BlN-2) actually represented an increase in the size of the roosting population. POBSP data indicate that most early visits occurred at times of year when this species was probably absent from the atoll.

Table BN-8. Recapture rates of adult Brown Noddies banded at Kure Atoll and recaptured there (expressed as percentages), 1959-69*.

Year Banded	n.	Year Recaptured 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1959	37	100.0	21.6 (0.0)	21.6 (0.0)	21.6 (0.0)	21.6 (0.0)	21.6 (10.8)	18.9 (2.7)	16.2 (13.5)	2.7 (0.0)	2.7 (0.0)	2.7 (2.7)
1962	35	--	--	--	100.0	20.0 (2.9)	17.1 (0.0)	17.1 (5.7)	14.3 (11.4)	2.9 (0.0)	2.9 (0.0)	2.9 (2.9)
1963	44	--	--	--	--	100.0	18.2 (0.0)	18.2 (2.3)	15.9 (13.6)	2.3 (0.0)	2.3 (0.0)	2.3 (2.3)
1964	243	--	--	--	--	--	100.0	13.2 (1.2)	12.4 (10.7)	1.6 (0.0)	1.6 (0.0)	1.6 (1.6)
1965	36	--	--	--	--	--	--	100.0	5.6 (5.6)	2.8 (0.0)	2.8 (0.0)	2.8 (2.8)
1966	157	--	--	--	--	--	--	--	100.0	0.6 (0.0)	0.6 (0.0)	0.6 (0.6)
1969	13	--	--	--	--	--	--	--	--	--	--	100.0

* First figure represents the percentage of birds known to have been alive and the second figure is the percentage of birds captured.

Table BlN-1. Previous records of Black Noddies on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	0	(Munter, 1915).
1923	April 17-22	fairly common	(Wetmore, ms.).
1957	June 5	44	(Kenyon and Rice, 1958: 190).
1958	May 9	6	On beach (Rice, pers. corr.).
1959	October 3-8	7	(Robbins, 1966: 53).
1960	March 28	1	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	20-30	Roosting in Scaevola (Udvardy and Warner, 1964: 2).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	50	(Robbins, 1966: 53).
1963	February 3-7	0	(Robbins, 1966: 53).

POBSP estimates were based on counts made in conjunction with shorebird, or booby and frigate censuses. The latter were more accurate because they were made at dusk as the noddies returned to roost. Allowing for slight discrepancies in census techniques, it appeared that there was little change in population size from 1964 to 1969.

Both adult and young Black Noddies roosted on the island. In 1967, 36.7 percent of the birds handled were immatures or subadults. At least three adults were actively molting and had bare brood patches, indicating that they had recently bred. The Black Noddies at Kure were probably a post-breeding population from Midway Atoll, where thousands breed, mainly in winter.

Annual Cycle

Black Noddies were generally absent from late December through mid-March. Small numbers were present in late March and April, except in March 1964 when large Black Noddy flocks were seen on two nights flying over the lagoon. After April, the population increased until a peak was reached in: early June (1967, 1968), late June (1966), and August (1964,

Table BlN-2. POBSP semi-monthly estimates of Black Noddies on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	3	0	-	2	-	1
16-31	-	1	1	-	-	-	0
February							
1-15	-	0	0	0	0	-	0
16-28	0	0	0	-	-	-	1
March							
1-15	-	0	0	-	-	-	0
16-31	-	1,000	10	-	*	0	20
April							
1-15	-	*	25	-	-	-	200
16-30	-	250	10	15	-	-	300
May							
1-15	100	250	15	1,000	450	-	1,000
16-31	-	250	15	1,000	600	1,250	850
June							
1-15	-	250	55	1,000	2,000	1,250	850
16-30	*	175	110	2,000	2,000	1,250	*
July							
1-15	-	500	360	479	2,000	1,250	-
16-31	-	750	500	700	-	1,250	-
August							
1-15	-	1,000	1,000	1,000	-	500	-
16-31	-	1,000	-	800	-	800	-
September							
1-15	-	600	-	1,200	-	900	-
16-30	*	400	-	1,200	-	500	-
October							
1-15	*	100	-	-	-	*	-
16-31	*	50	-	-	-	*	-
November							
1-15	200	25	-	-	-	*	-
16-30	75	0	0	-	-	*	-
December							
1-15	75	0	1	-	-	*	-
16-31	300	0	-	2	-	6	-

* Birds present, number unknown.

1965). Large influxes of Black Noddies were noted 10 to 14 May 1966, ca. 3 June 1967, and 12 to 15 May 1969. By October the population began to decline until a low point was reached in late November. No indication that this species bred at Kure was noted during POBSP studies.

Ecology

During the day Black Noddies roosted commonly on the beaches with Brown Noddies. They also fed on small fish along the water's edge, especially in the lagoon. A few were present in *Scaevola* and on man-made structures.

At night they roosted in *Scaevola*, mainly along the southwest beach and in the southwest portion of the island (Fig. BlN-1). On some nights a few also roosted in the casuarinas, on the radar reflector and on the pier.

In 1966 when the large number of noddies arrived, they roosted along the beach-*Scaevola* ecotone but later moved further inland. Some individuals roosted along the northwest and southeast beaches after the population peaked.

Banding and Movements

The POBSP banded 401 Black Noddies at Kure Atoll (Table BlN-3). Three adults have been recaptured: one banded on 11 August 1964 was captured on 5 June 1966 at Kure, another banded on 18 July 1966 was recaptured on Whale Island, French Frigate Shoals, on 6 June 1967, and a third banded on 10 May 1966 was found at Midway Atoll on 11 December 1967. Robbins banded 5 adults in August 1965, but none was recaptured.

Table BlN-3. Black Noddies banded at Kure Atoll by the POBSP.

Year Banded	Adults	Subadults	Totals
1963	17	0	17
1964	62	0	62
1965	16	10	26
1966	180	13	193
1967	36	20	56
1969	47	0	47
Totals	358	43	401

Recaptured at Kure were eight Black Noddies banded by POBSP personnel on other islands or atolls: Southeast Island, Pearl and Hermes Reef (3), Lisianski (1), Whale Island, French Frigate Shoals (3), and Sand Island,

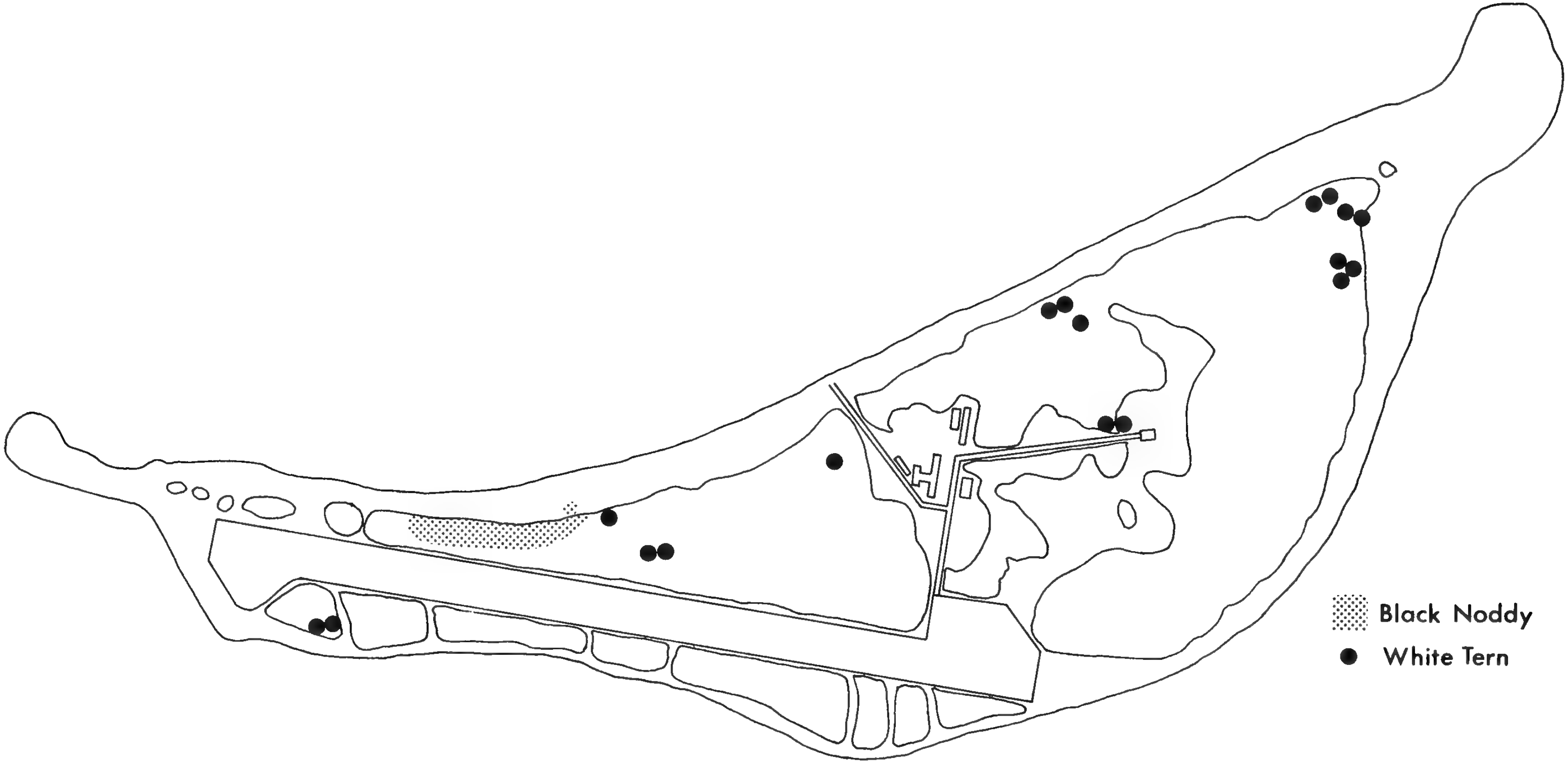

Figure BlN-1. Main Black Noddy roosting area and White Tern breeding sites of Green Island, Kure Atoll.

Johnston Atoll (1). One of these birds, a subadult banded on Whale on 5 June 1967 was captured at Kure on 7 July 1967. The others were all recaptured at least one year after banding.

In addition, 16 adults banded in January and February 1964 by Eugene Kridler on Sand Island, Midway Atoll, were captured in the following months: August 1964 (1), May 1966 (8), June 1966 (3), May 1967 (1), and May 1969 (2).

WHITE TERN *Gygis alba*

Status

Uncommon visitor and spring-summer breeder: *ca*. 5 to 6 pairs annually. Present all year with peak populations from April through August. Breeds from April until at least September.

Populations

White Terns were first recorded from Kure Atoll by Lt. John T. Diggs of the U.S.S. *Hermes* on 15 September 1918. Other earlier observers (Table WT-1) saw them infrequently and in small numbers.

During the POBSP survey of the atoll the population size remained fairly constant (Table WT-2). The maximum estimate made in July 1968 resulted from an influx early in the month of at least 25 adults that remained until early August. Since no more than 12 White Terns bred in any one year, most of the population represented non-breeding birds, probably from Midway Atoll.

Table WT-1. Previous records of White Terns on Green Island, Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1915	March 28	0	(Munter, 1915).
1918	September 15	?	Offshore (R.G. 45, Nat. Archives, Report of Commanding Officer U.S.S. *Hermes* to Commandant 14th Naval District).
1923	April 17-22	0	(Wetmore, ms.).
1957	June 5	1	Offshore (Kenyon and Rice, 1958: 190).
1958	May 9	6	Over lagoon (Rice, pers. corr.).
1959	October 3-8	2	(Robbins, 1966: 53).

Table WT-1. (continued)

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1960	March 28	0	(Robbins, 1966: 53).
1961	January 19-21	0	(Robbins, 1966: 53).
	September 12-14	rare	(Udvardy, 1961: 46).
1962	February 2-4	0	(Robbins, 1966: 53).
	August 6-8	10	5 nests (Robbins, 1966: 53).
1963	February 3-7	0	(Robbins, 1966: 53).

Annual Cycle

White Terns were present throughout the year with peak populations from April through August. POBSP data suggest that some, if not all, of the breeding population left the atoll during winter, as very few terns were seen at this time.

The breeding cycle was constructed from data from the 19 nests that were found. Only the 1967 and 1968 data were sufficient to compare yearly differences in the timing of the cycle.

Egg laying began in mid-April and continued until at least 25 June. In 1967 three of four eggs (75 percent) were laid the first week of May, while one year later 67 percent were laid between 26 April and 11 May. When all data are combined, there was a peak period of egg laying the last week in April and first week of May (Fig. WT-1).

The first egg hatched *ca.* 23 May. Hatching continued until *ca.* 30 July, with hatching peaks in 1967 and 1968 five weeks later than laying peaks.

White Terns fledged 42 to 48 days (1965 and 1968 data, n=3) after hatching. Thus fledging occurred from early July through early September, although one nestling may have been present in October since an adult carrying a fish was seen on 21 October 1964.

Nesting Success

Table WT-3 summarizes White Tern productivity on the island. Although only a few young were produced each year, they represented a relatively large percentage of the total eggs laid.

The most accurate success data were for 1968 when all six eggs that were found hatched, and four of the young fledged.

Table WT-2. POBSP semi-monthly estimates of White Terns on Green Island, Kure Atoll, 1963-69.

	1963	1964	1965	1966	1967	1968	1969
January							
1-15	-	0	0	-	0	-	0
16-31	-	1	5	*	-	-	1
February							
1-15	-	*	1	3	4	-	2
16-28	-	*	12	-	-	-	2
March							
1-15	-	15	5	-	-	-	5
15-31	-	15	8	-	10	4	20
April							
1-15	-	20	13	-	-	-	20
16-30	-	20	15	10	-	-	12
May							
1-15	6	20	15	15	25	-	20
16-31	-	25	15	15	25	30	30
June							
1-15	-	25	15	15	25	30	50
16-30	-	25	15	15	25	30	*
July							
1-15	-	20	15	15	25	55	-
16-31	-	15	20	15	-	55	-
August							
1-15	-	30	29	15	-	*	-
16-31	-	30	-	6	-	*	-
September							
1-15	-	10	-	12	-	*	-
16-30	*	10	-	8	-	*	-
October							
1-15	*	10	-	-	-	*	-
16-31	*	10	-	-	-	4	-
November							
1-15	10	5	-	-	-	4	-
16-30	0	5	3	-	-	3	-
December							
1-15	1	5	1	-	-	3	-
16-31	0	5	-	0	-	2	-

*Birds present, number unknown.

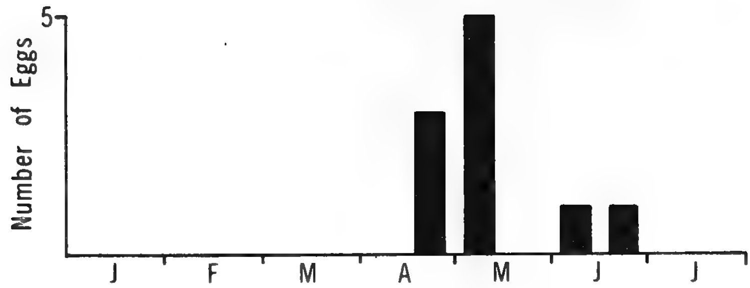

Figure WT-1. Number of White Tern eggs laid each semi-monthly period on Green Island, Kure Atoll, 1967-68 (combined data).

Table WT-3. Productivity of White Terns on Green Island, Kure Atoll, 1964-69.

Year	Maximum Number of Eggs	Maximum Egg Count	Maximum Nestling Count	Number Fledged	Percent Fledged
1964	4	1	4	4	--
1965	3	2	2	2	66.7
1966	2	2	1	1	50.0
1967	5	2	4*	4	80.0
1968	6	6	6	4	66.7
1969	1	1*	0	?	--

* Number remaining in late June.

Ecology

Figure B1N-1 shows the general location of all White Tern nests found on the island. In 1968, 67 percent of the nests were located in the same general area as in 1967, in one case on the same bush, indicating a certain amount of nest-site specificity.

Seventeen of these nests were on Scaevola while one was on Tournefortia. In all cases the single egg was placed on a branch where there was enough level area, or there were supporting projections, to prevent the egg from rolling off. In 1968 three nests were in crotches of limbs, two in depressions, and one between two branches. No materials were added to the nests.

Most nests were surrounded by continuous Scaevola with a considerable amount of open area near the nests, but three were in open areas of

scattered Scaevola and Verbesina. The average height off the ground was 23.5 inches (n=4) in 1967 and 37.5 inches (n=6) in 1968, with a range of 20 inches to 6.5 feet. In 1967 four nests were at least 10 feet from the beach-Scaevola ecotone.

Non-nesting White Terns roosted in Casuarina, Scaevola, Tournefortia and man-made structures such as the radar reflector. The main roosting area was in the casuarinas behind the barracks. Usually they roosted alone or in twos, but occasionally small flocks were found in the casuarinas.

Banding and Movements

The POBSP banded 60 adult White Terns (2 in 1963, 17 in 1964, 8 in 1965, 1 in 1966, 2 in 1967, and 30 in 1969) and Robbins banded one in October 1959. Only two of these birds were recaptured--one 1964 bird in 1969 and a 1965 bird in 1966.

Eleven nestlings were also banded (2 in 1964, 2 in 1965, 4 in 1967, and 3 in 1968). None was recaptured. No White Terns banded on other islands were found at Kure.

HORNED PUFFIN — Fratercula corniculata

During the winter of 1962-63 several Horned Puffins were found on the Northwestern Hawaiian Islands. Fisher (1965) reported that in January 1963 one live bird was found at Kure Atoll. Robbins informs me (personal communication) that this bird was found on 27 January by a Navy pilot and that he retrieved it as a specimen on 3 February along with 2 more found that day. In addition, another one was found dead on 5 February and another the next day, thus accounting for the five carcasses reported in Robbins (1966). The POBSP found one washed up on the beach on 20 February 1963.

Horned Puffins have also been recorded in the Northwestern Hawaiian Islands from Midway Atoll, Pearl and Hermes Reef, and Laysan (Clapp and Woodward, 1968).

SHORT-EARED OWL — Asio flammeus (flammeus?)

Short-eared Owls have been seen several times at Kure Atoll (Table SEO-1). They were recorded as early as 6 October and as late as 29 April. Usually a single owl was seen flying over the island, mainly over the central plain, but on three occasions two were recorded. The few pellets that were found indicated that they fed on Polynesian rats (Rattus exulans).

Based on a single specimen, the owls at Kure are from the Eurasian and North American population (Asio f. flammeus), rather than the closer Hawaiian population (Asio flammeus sandwichensis) (Clapp and Woodward, 1968).

The temporal distribution of the records (mainly fall and winter) supports this evidence or origin as that is the time to expect northern migrants in the Hawaiian area.

Table SEO-1. Observations of Short-eared Owls on Green Island, Kure Atoll.

Date		Number	Observer	Remarks and References
1962	February 2-4	2	C.S. Robbins	(Robbins, 1966: 53).
1963	October 6	1	POBSP	Flying over central plain.
	November 13	1	POBSP	Near the central plain; flushed from ground.
	December 11	1	H.I. Fisher	(Fisher, 1965: 357).
1964	February 12	1	POBSP	Collected.
	March 24	1	POBSP	On ground near central plain.
	November 15	1	POBSP	Flying over north roost.
	December 1-15	1	POBSP	Seen on 3 different occasions.
	December 24	2	POBSP	Under Scaevola.
1965	January 29, 30, 31	1	POBSP	Feeding on rats on 29 January.
	February 10	1	POBSP	--
	March 17	1	POBSP	--
1966	December 31	1	POBSP	--
1967	February 9, 10	1	C.S. Robbins	Flying over central plain.
1968	November 14-26	1	POBSP	Seen several times.
	December 17	1	POBSP	Flying over central plain.
	December 19	1	POBSP	Flying over runway.
1969	February 2	1	POBSP	Flying over lagoon.
	February 9	1	POBSP	Flying over Scaevola near south antenna field.

Table SEO-1. (continued)

Date		Number	Observer	Remarks and References
1969	February 10	2	POBSP	Flying over south antenna field.
	March 18	1	POBSP	Sitting in south antenna field.
	April 29	1	POBSP	Flying over runway.

SKYLARK — Alauda arvensis pekinensis

On 29 September 1963 two sparrow-like birds with white outer tail feathers were seen. Ludwig shot one of these near the east end of the runway, but lost it in a dense Scaevola-Ipomoea tangle. Another individual of this type was seen flying overhead on 5 and 6 October. On 7 October a Skylark, which Ludwig subsequently shot, was seen with a group of American Golden Plovers along the road to the transmitter building. It proved to be a female.

This is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

BARN SWALLOW — Hirundo rustica

On the evening of 25 September 1964 two Barn Swallows, believed to be an adult and immature, were seen sitting on an antenna wire and flying over the central plain. Both were subsequently shot, but the specimens fell into dense vegetation and could not be found.

Barn Swallows have also been recorded in the Hawaiian Islands from Midway Atoll (Clapp and Woodward, 1968).

WATER PIPIT — Anthus spinoletta japonicus

Ludwig collected a very fat female Water Pipit on 25 October 1963 as it ran along the edge of Scaevola on the north beach.

This is the only record for the main or Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

RED-THROATED PIPIT — Anthus cervinus

Ludwig shot a winter-plumaged Red-throated Pipit as it flew over the Scaevola along the east beach on 26 September 1963.

This is the only record for the main or Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

HOUSE SPARROW   *Passer domesticus*

Woodward observed a male House Sparrow around the barracks on three different occasions, 18 to 20 June 1966. On at least one night it roosted in the casuarinas along the road to the pier. Possibly this sparrow came on a cargo plane which had arrived three days earlier.

This widespread species was introduced to Hawaii before 1870, and is now common on all the main islands of the Hawaiian Group, but this is the only record for the Northwestern Hawaiian Islands (Clapp and Woodward, 1968).

SNOW BUNTING   *Plectrophenax nivalis townsendi*

Sibley shot a female Snow Bunting on 10 March 1963 along the runway. This is the only specimen for the Hawaiian Islands (Clapp and Woodward, 1968).

Sand Island Avifauna

Chandler S. Robbins (personal communication) saw a small group of Black-footed Albatross at the west end of Sand Island on 25 March 1960.

On 12 September 1961 twelve Bristle-thighed Curlews and a number of Brown Noddies were seen on Sand Island (Udvardy and Warner, 1964). POBSP observers, in their infrequent visits to the island, recorded an additional seven species (Table SI-1). Only the Brown Noddy bred there. Since no nocturnal observations were made, it was not determined to what extent birds utilized Sand Island as a roosting site.

Specimens

Table S-1 lists the avian specimens known to have been collected at Kure Atoll by the POBSP, Chandler S. Robbins, and Alexander Wetmore. They are all in the collection of the United States National Museum.

Table SI-1. POBSP estimates of birds on Sand Island, Kure Atoll, 1964-68.

	1964				1965				1966		1967	1968	
Species	May 29	August 13	October 31	November 16	March 27	May 24	July 30	November 28	August 3	August 25	June 29	July 4	August 14
Sooty Shear-water	0	0	0	0	0	0	0	0	0	0	0	1*	0
Blue-faced Booby	0	3	2	3	0	0	1	0	0	0	2	0	0
Brown Booby	0	3	14	30	1	0	8	8	0	0	0	0	0
Wandering Tattler	1	1	1	0	0	0	0	1	0	10	2	2	0
Ruddy Turn-stone	9	7	16	9	0	2	5	13	0	13	0	16	0
Sanderling	0	0	0	0	0	3	0	0	0	0	0	0	0
Brown Noddy	200	167	185	100	65	180	136	7	120	52	200	200	200
Eggs	65	1	0	0	0	35	1	0	21	2	48	73	16
Young	0	54	0	0	0	0	16	0	30	14	43	0	63
Black Noddy	50	64	1	0	5	50	142	0	3	55	0	10	30

* Found dead.

Table S-1. Avian specimens known to have been collected at Kure Atoll.

Species	Number of: Skins	Skeletons	Alcoholics	Totals
Black-footed Albatross	7	0	0	7
Laysan Albatross	9	6	1	16
Black-footed x Laysan Albatross	1	0	0	1
Northern Fulmar	1	3	0	4
Bonin Petrel	35	12	6	53
Kermadec Petrel	1	0	0	1
Murphy's Petrel	1	0	0	1
Wedge-tailed Shearwater	34	7	1	42
Sooty Shearwater	6	3	0	9
Christmas Shearwater	6	1	0	7
Leach's Storm Petrel	1	0	1	2
Sooty Storm Petrel	7	0	0	7
Red-tailed Tropicbird	19	2	2	23
Blue-faced Booby	12	2	10	24
Brown Booby	11	1	5	17
Red-footed Booby	17	3	0	20
Great Frigatebird	28	1	0	29
Lesser Frigatebird	1	0	0	1
Black-crowned Night Heron	1	0	0	1
Emperor Goose	1	0	0	1
European Widgeon	1	0	0	1
Pintail	6	0	0	6
Tufted Duck	1	0	0	1
Peregrine Falcon	1	0	0	1
Dotterel	1	0	0	1
American Golden Plover	12	2	0	14
Ruddy Turnstone	18	1	0	19
Pintail Snipe	1	0	0	1
Common Snipe	1	0	0	1
Bristle-thighed Curlew	4	2	0	6
Wood Sandpiper	2	0	0	2
Wandering Tattler	5	1	0	6
Lesser Yellowlegs	1	0	0	1
Sharp-tailed Sandpiper	2	0	0	2
Pectoral Sandpiper	6	0	0	6
Dunlin	1	0	0	1
Long-billed Dowitcher	1	0	0	1
Western Sandpiper	1	0	0	1
Bar-tailed Godwit	1	0	0	1
Ruff	1	0	0	1
Sanderling	1	0	0	1
Red Phalarope	2	0	0	2
Ring-billed Gull	1	0	0	1
Herring Gull	8	0	0	8
Slaty-backed Gull	1	0	0	1

Table S-1. (continued)

Species	Number of: Skins	Skeletons	Alcoholics	Totals
Glaucous-winged Gull	9	0	0	9
Black-legged Kittiwake	2	0	0	2
Arctic Tern	1	0	0	1
Sooty Tern	23	4	0	27
Gray-backed Tern	4	0	0	4
Brown Noddy	19	2	2	23
Black Noddy	5	1	0	6
White Tern	7	0	0	7
Horned Puffin	2	2	0	4
Short-eared Owl	1	0	0	1
Skylark	1	0	0	1
Water Pipit	1	0	0	1
Red-throated Pipit	1	0	0	1
Snow Bunting	1	0	0	1
Totals	356	56	28	440

KURE REPTILES

Four species of reptiles were recorded from the atoll. Green Sea Turtles were occasionally seen swimming in the lagoon and a small population of Stump-toed and House Geckos was resident on Green Island.

There was one hypothetical record of Hawksbill Turtles.

Species Accounts

HAWKSBILL TURTLE *Eratmochelys imbricata*

Morrell (1841) reported that two Hawksbill Turtles were seen 13 to 14 July 1825. The validity of this record is uncertain.

GREEN SEA TURTLE *Chelonia mydas*

Morrell (1841) found Green Turtles abundant at Kure in 1825. Although few of the early visitors to the atoll reported them (Table GT-1), they probably killed them for food and were thus responsible for these reptiles' scarcity today.

During POBSP studies, turtles, presumably Green, were occasionally seen, generally swimming in the lagoon (Table GT-2). They were found only four times on land and there was no indication of breeding at the atoll.

Table GT-1. Previous records of Green Sea Turtles at Kure Atoll.

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1825	July 13-14	great abundance	(Morrell, 1841).
1859	late June or early July	plenty	(Brooks, 1860).
1870 to 1871	October 29 to January 4	?	4 large turtles captured on sandspit (Read, 1912).
1881 to 1882	December 30 to January 1	?	Collected 6 turtles and found 2 rotten eggs (Hornell, 1934).
1886	July 15-August 18	?	Turtles available as food (Hawaiian Almanac and Directory, 1887).
1936	April 5-13	1	1 turtle seen (R.G. 37 Report on the Survey of Pearl and Hermes Reef and Kure Ocean Island).

Table GT-2. POBSP observations of Green Sea Turtles at Kure Atoll, 1963-69.

Date of Observation		Number	Remarks
1963	October 29	1	--
	November 6	1	In lagoon.
1964	May 29	1	On Sand Island; caught, tagged, photographed and released.
	July 7	2	Offshore near the west end of the runway.
	August 13-28	?	Numerous tracks and diggings found along southeast beach.
	October 19	1	2' long; offshore near the west end of the runway.
1965	May 1	2	Small; off east beach.
	July 20-31	3	In lagoon; 2-3' diameter.

Table GT-2. (continued)

Date of Observation		Number	Remarks
1967	June 10	1	20"; in lagoon along west beach.
	June 29	1	20"; swimming in lagoon near the pier.
	July 2	1	ca. 3' long; in lagoon; caught, photographed, tagged and released.
	July 8	1	Off west point.
1968	July 31	1	Off southeast beach.
	August 17	1	Off pier.
	August 26	2	Off southwest beach.
	November 11	1	On Sand Island; 250-300 pounds.
	December 13	1	On northwest beach.
1969	January 25	2	Off west point.
	January 27	3	Off southeast beach; 20-24" carapace.
	February 16	1	Off northeast beach; 18" long.
	February 21	1	Off southeast beach.
	March 2	1	Off northeast beach.
	March-April	?	Occasionally sighted, largest individual not over 24".
	May	?	Small individuals continued to be sighted around reef.

STUMP-TOED GECKO *Gehyra mutilata*

HOUSE GECKO *Hemidactylus frenatus*

Two species of geckos, the Stump-toed and the House, were recorded on Green Island. Based on the specimens collected, the former species was the more common. Undoubtedly they were accidentally introduced from Midway Atoll.

Geckos were seen in small numbers around the barracks, the transmitter building, and the casuarinas along the southwest beach. They were

noticed more commonly in late spring and summer than during the rest of the year. Nothing was known of their life history at the atoll.

KURE MAMMALS

Nine species of mammals were recorded from Kure Atoll. Two, the Bottle-nosed Dolphin and the Spinner Dolphin, were found in the lagoon or just outside the reef, while the Sperm Whale and Goose-beaked Whale washed up on the beach. The Squirrel Monkey, the Pig, and the Domestic Dog were brought to the LORAN station as pets. The Polynesian rat was probably accidentally introduced by the Polynesians, and the Hawaiian Monk Seal evolved in the Hawaiian area.

Species Accounts

SQUIRREL MONKEY *Saimiri* sp.

A male Squirrel Monkey was released by the Coast Guard in late 1961. It remained on Green Island in a semi-wild state until January 1967 when it disappeared. Before it disappeared it was frequently seen on the island, and in 1965 it began sleeping on the top of the radar reflector where it could be fed by hand. It was observed taking an albatross egg, feeding on *Scaevola* berries and leaves, and chasing roosting Red-footed Boobies and Great Frigatebirds. Apparently it only rarely disturbed the birds and, in fact, appeared to be afraid of some, such as breeding Sooty Terns.

POLYNESIAN RAT* *Rattus exulans*

Status

Abundant resident, populations ranging from 20 to 70 animals per acre in 1964 to 1965. Most common in summer and fall.

Populations

Polynesian rats were first recorded at Kure Atoll by George H. Read (1912) of the U.S.S. *Saginaw*, who reported, "Rats more in evidence of late. At first small and timid they are now growing larger and bolder." All biologists visiting the atoll prior to POBSP investigations also recorded these mammals. Although unproven, it is probable that the Polynesians accidentally introduced the rats long before Europeans discovered the atoll.

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* Wirtz (ms.) studied this species intensively at Kure from 1963 to 1965. Pertinent data are summarized here from his paper. Readers are referred to his work for details.

Population estimates were made from March 1964 to May 1965 and in April 1966, by live trapping in a 6.94-acre study area of mixed habitats adjacent to the north antenna field. Figure PR-1 summarizes the 1964-65 data. In late April 1966 there were an estimated 340 rats in the area.

Mean monthly density from March 1964 to May 1965 was 45 animals per acre, with a range of 20 to 77. Projecting for the whole island gave an average total population of 6,480, fluctuating from 2,880 to 11,090 animals.

Although little or no quantitative data were collected from 1966 to 1969, observations indicated that rats were extremely abundant in 1966, almost absent in 1967, and common again, although less so than in 1966, in 1968 and 1969.

Annual Cycle

Polynesian rats were most abundant during the fall. They were uncommon from January to May and then began increasing in June, reaching a peak in September or October.

In fall 1963 there were an estimated 7,200 rats, or 50 per acre, on the island. From December 1963 to February 1964 the population declined to an estimated 30 animals per acre, and then increased to a peak of 75 rats per acre after the breeding season. Following this peak, numbers declined to about 20 rats per acre by 1965.

Breeding occurred from January through September, with most litters being produced from March through August. The average litter size was 4.07. In a sample of 100 live-trapped adult females, 7 produced 2 litters in a year, 1 produced 3, 47 produced 1, and 45 produced none. The observed pregnancy rate in the study area was about 90 litters per season, or about 360 new rats per breeding season.

Ecology

Polynesian rats occurred in all the vegetated areas on the island. They appeared especially abundant in the central plain and adjacent areas. The garbage area near the barracks was also attractive to them, and during the fall when they were abundant, they would often be found inside the buildings.

The diet of Polynesian rats consisted of 62 percent plant material, 30 percent insects, and 8 percent vertebrate flesh. They were known to have eaten the seeds of *Boerhavia*, the tender shoots and heads of *Eragrostis*, the berries of *Scaevola*, and the seeds of *Lepidium*, *Tribulus*, and *Sicyos*. Insect families identified from fragments in stomachs were *Scarabaeidae*, *Elateiidae* (larvae), *Noctuidae* (larvae), *Blattidae*, and *Formicidae*. The relationship of rats and birds was discussed earlier in this paper.

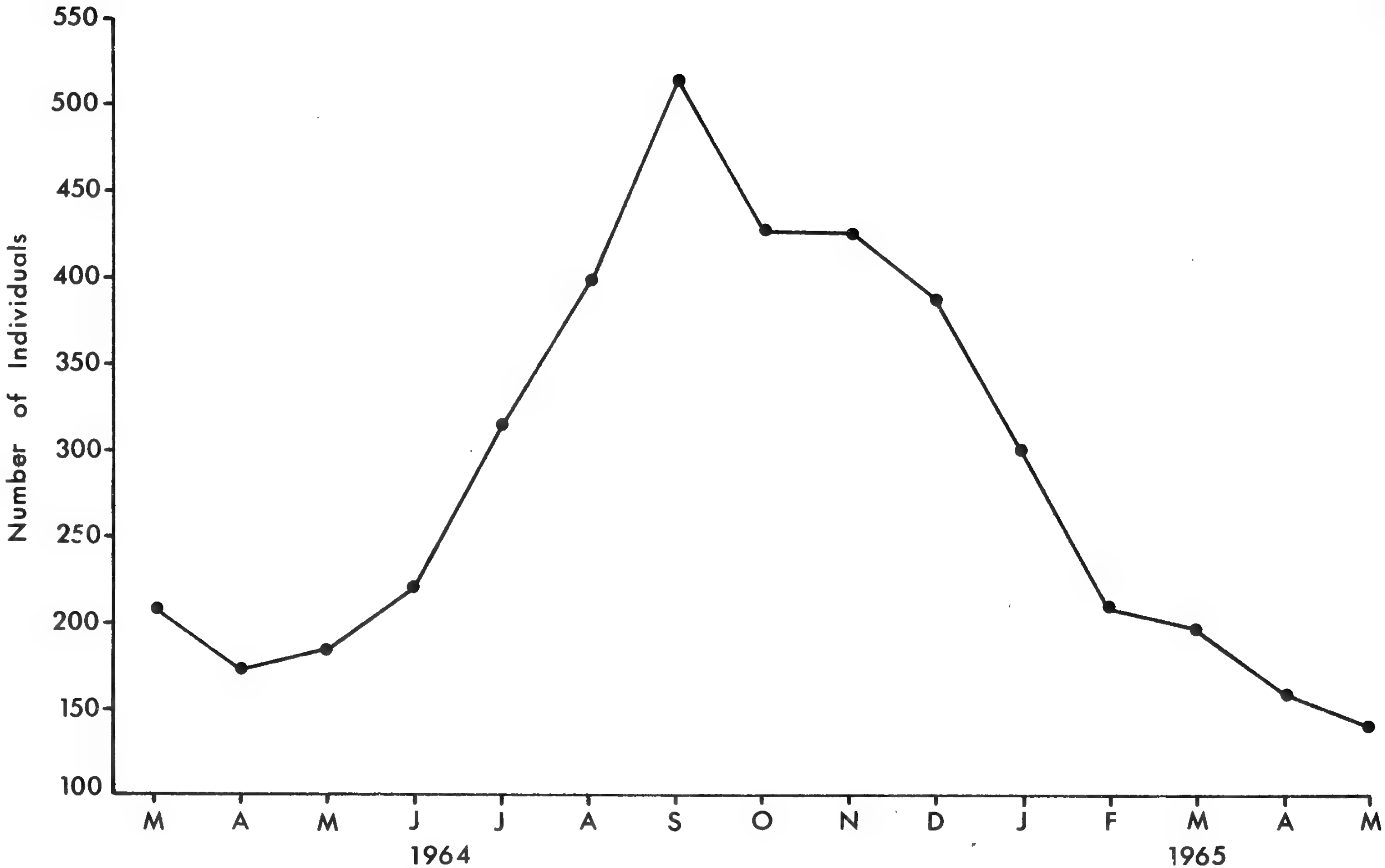

Figure PR-1. Population size of Polynesian Rats in a 6.94 acre study area on Green Island, Kure Atoll, March 1964-May 1965.

GOOSE-BEAKED WHALE *Ziphius cavirostris*

On 25 July 1966 a dead Goose-beaked Whale was found washed up on the northwest beach. This animal had been dead for about a day and large chunks of flesh were missing, probably as a result of sharks. Photographs and measurements were taken and the skull saved.

Ziphius cavirostris ranges in the Pacific Ocean from the Bering Sea to Baja California, eastern Siberia and Japan, and off the Hawaiian and Midway Islands (Hershkovitz, 1966).

SPERM WHALE *Physeter catadon*

On 23 April 1964 Coast Guard personnel found two Sperm Whale mandibles on the reef. These bones were collected and returned to the lab where they remained during the rest of the POBSP study period.

Another Sperm Whale was recorded on 8 July 1967 when the remains of a 30- to 40-foot individual washed up on the south beach near the channel to the lagoon. This animal was photographed, but no bones were collected.

This species is found in all seas from the Arctic to Antarctic Oceans (Hershkovitz, 1966).

HAWAIIAN SPINNER DOLPHIN *Stenella roseiventris*

BOTTLE-NOSED DOLPHIN *Tursiops truncatus*

Rice (1960a) saw about 12 Bottle-nosed Dolphins within 2 kilometers of the reef on both 5 June 1957 and 9 May 1958.

Dolphins were recorded infrequently in the lagoon or beyond the reef during POBSP studies. Due to the unfamiliarity of most observers with cetaceans, most of these mammals were unidentified. However, two species, the Hawaiian Spinner Dolphin and the Bottle-nosed Dolphin, were definitely identified by Robert L. Brownell. The latter species was seen on 16 November 1964 when 50 to 60 followed a boat in the lagoon, and on 21 September 1968 when several were seen off the south point. The former species was recorded twice: on 14 August 1968 when three schools totaling 80 to 100 individuals were seen east of Sand Island and 28 August 1968 when they were seen in the lagoon. Table PO-1 lists the remaining sightings of unidentified cetaceans.

Tursiops truncatus is widely distributed in temperate and tropical seas (Rice and Scheffer, 1968), and *Stenella roseiventris* is found in the tropical eastern and central Pacific Ocean (Robert Brownell, personal communication).

Table PQ-1. POBSP observations of unidentified cetaceans at Kure Atoll, 1964-69.

Date of Observation		Number Seen	Remarks
1964	January 1	25+	East of Green Island.
	September 18	school	Within 100 yards of eastern reef.
	September 25	school	Close to eastern reef.
	October 2	?	Off eastern reef.
	October 4	several	Off northeast reef; leaping out of water.
	November 27	20	Swimming slowly up eastern edge of the reef.
1965	January 21	12	Swimming northeast along outer edge of reef.
	May 24	50±	In lagoon near Sand Island.
1969	January 18	2	Near Sand Island.
	April 16	30±	Off south side of Green Island.
	May 7	50±	Off reef beyond Sand Island.

HAWAIIAN MONK SEAL — *Monachus schauinslandi*

Status

Common permanent resident; 150 to 200 animals. Population apparently decreasing. Pups usually born from February to June.

Populations

Hawaiian Monk Seals were first recorded from Kure Atoll by Morrell in 1825 (Table MS-1). Most other earlier visitors also noted these mammals, but unfortunately did not quantify their observations. Undoubtedly seals were common in the 1800's, but the population probably fluctuated drastically with the repeated killings by the crews of wrecked ships. For example, the crew of the *Parker* reportedly killed 60 seals during their stay on the island in 1842-43 (Whalemen's Shipping List, November 7, 1843). Lt. Commander Montgomery Sicard, captain of the U.S.S. *Saginaw*, reported (in Annual Report of the Secretary of the Navy on the Operation of the Department for the Year 1871) that "I commenced by sending out parties to

kill seal...but after about a month I found that, owing to the rapid diminuation of the seal, I was obliged to cut the allowance down, and only killed one seal...per day for the whole crew." Thus at least 60 Monk Seals were killed in 1870.

Kenyon and Rice placed the Kure population at 128 in winter 1956-57 and 142 in winter 1957-58. Based on the number of seals tagged and the number of previously tagged seals seen, the island population was 139 in 1964 and 141 in 1965. Wirtz (1968) estimated the total atoll population as 200 for both years. From the fall of 1963 to the summer of 1965, 112 adults, 22 subadults, and 71 juveniles (57 of them born at Kure) were tagged; thus the previous estimates were probably accurate.

Besides these total population figures, population estimates were made at weekly or semi-monthly intervals by counting seals on Green Island as an observer walked around the island. These counts varied yearly. In 1964 and 1969 only those seals seen on Green Island were counted; in 1965 and 1968 all seals seen on Green Island, and Sand Island as seen from Green Island, were enumerated and the counts separated. However, in 1966 and 1967, although the same method was used, the counts were not separated. Finally, several ground counts were made on Sand Island. These data are summarized by month and year in Tables MS-2 to 5.

These data suggested that Monk Seals were decreasing as most counts made from 1967-69 were lower than previous counts. Especially significant were the 1969 counts when very few seals hauled out on Green Island. This decrease probably resulted from the increased disturbance by man and by the station dogs who often chased the seals back into the water after they had hauled out. Continuous harassment of this type will lead to the disappearance of this mammal from Green Island. Kenyon (in prep.) discusses in detail disturbance as a population control factor.

Annual Cycle

Hawaiian Monk Seals were present throughout the year, with peak populations on Green Island from December through May. When Sand Island washed away, all seals hauled out on Green Island. POBSP data suggest that after the main pupping season, adult seals moved either to Sand Island or away from the atoll.

Actual copulation was not observed so it was not known when the breeding season began; it probably started in late summer or fall. The first pups were born on 20 February 1964, 14 February 1965, and 18 January 1969, and the last ones in late July 1964 and 9 June 1965. Figure MS-1 shows the number of pups born each semi-monthly period in 1964 and 1965. Pups spend about 5 weeks ashore before leaving (Wirtz, 1968).

Table MS-1. Previous records of Hawaiian Monk Seals at Kure Atoll.

Date of Survey	Population Estimate	Breeding Status, Remarks, References
1825 July 13-14	?	"the shores...were lined with sea elephants" (Morrell, 1841: 218).
1837 July 9 to 1838 ?	considerable number	(Hawaiian Spectator, July 1838).
1842 September 24 to 1843 May 2	?	Killed ca. 60 seals (Whalemen's Shipping List, November 7, 1843).
1870 October 29 to 1871 January 4	?	"main source of food will be the seal" (Read, 1912: 32).
1910 January 23	?	Number of sea lions (Log of _Thetis_, R.G. 26, U.S. Nat. Archives).
1915 March 28	large number	Hauled out on the beach (Munter, 1915: 136).
1923 April 17-22	40-50	At least one pup born (Wetmore, ms.).
1934 June 23	50-60	(R.G. 26, U.S. Nat. Archives, Cruise report for _Itasca_ for month of June 1934).
1936 April 5-13	?	Photographs of U.S.S. _Oglala_ (R.G. 80, U.S. Nat. Archives).
1949 Summer	20-30	(Bailey, 1952: 19).
1951 August 2	30-40	Aerial survey (Bailey, 1952: 19).
October 12	ca. 70	(Bailey, 1952: 19).
1956 December 9 to 1957 June 5	128	25 pups born in spring of 1957 (Kenyon and Rice, 1959: 221).
1957 December 18 to 1958 June 28	142	25 pups born in spring of 1958 (Rice, 1960b; 379).
1959 September 28	53	(Robbins, 1966: 54).
October 3	59	(Robbins, pers. comm.).

Table MS-1. (continued)

Date of Survey		Population Estimate	Breeding Status, Remarks, References
1960	March 25	40-60	(Robbins, pers. comm.).
1961	September 12-14	65-70	(Udvardy and Warner, 1964: 3).

Table MS-2. Summary of POBSP Hawaiian Monk Seal Counts on Green Island, Kure Atoll, 1964-69.

Date		Number of Counts	Average Number Seen	Range
January	1964	2	28.0	22-34
	1965	4	27.5	8-74
	1969	4	1.3	1-3
	Total	10	17.1	1-74
February	1964	4	34.3	24-42
	1965	4	22.3	9-35
	1969	4	1.0	1-2
	Total	12	19.2	1-42
March	1964	4	24.5	21-30
	1965	4	46.7	31-71
	1967	1	10.0	-
	1969	4	5.5	2-8
	Total	13	24.4	2-71
April	1964	1	26.0	-
	1965	4	53.0	32-65
	1969	5	6.2	4-8
	Total	10	26.9	4-65
May	1965	5	40.4	25-61
	1969	4	14.3	10-20
	Total	9	26.6	10-61
June	1964	2	18.5	12-25
	1965	3	30.3	23-38
	1968	4	13.0	5-17
	1969	3	13.3	11-15
	Total	12	18.3	5-38

Table MS-2. (continued)

Date		Number of Counts	Average Number Seen	Range
July	1964	5	22.0	17-26
	1965	3	30.0	23-38
	1968	3	5.0	0-12
	Total	11	19.5	0-38
August	1964	4	16.0	9-23
	1965	1	7.0	-
	1966	1	11.0	-
	1968	2	2.0	0-4
	Total	8	10.8	0-23
September	1964	4	11.5	9-19
	1966	2	21.0	11-31
	1969	4	0.8	0-2
	Total	10	9.1	0-31
October	1964	6	7.2	2-13
November	1964	5	21.4	13-36
December	1964	5	41.8	16-78
	1968	1	4.0	-
	Total	6	35.5	4-78

Table MS-3. Summary of POBSP Hawaiian Monk Seal counts on Green and Sand Islands, Kure Atoll*, 1965-68.

Date		Number of Counts	Average Number Seen	Range
January	1965	3	62.7	48-74
February	1965	1	53.0	-
March	1965	4	71.0	51-85
April	1965	4	80.3	55-92
	1966	2	33.0	22-44
	1967	1	24.0	-
	Total	7	58.7	22-92

Table MS-3. (continued)

Date		Number of Counts	Average Number Seen	Range
May	1965	3	60.3	52-69
	1966	4	36.3	25-46
	1967	4	30.0	22-36
	Total	11	40.6	22-69
June	1965	3	39.7	32-47
	1966	2	28.0	24-32
	1967	2	16.0	15-17
	1968	4	17.3	7-23
	Total	11	25.1	7-47
July	1965	2	29.5	26-33
	1966	2	19.0	16-22
	1968	2	12.5	8-17
	Total	6	20.3	8-33
August	1965	1	14.0	-
	1966	1	8.0	-
	Total	2	11.0	8-14

Table MS-4. Summary of POBSP Hawaiian Monk Seal Counts on Sand Island, Kure Atoll*, 1965-68.

Date		Number of Counts	Average Number Seen	Range
January	1965	3	30.0	0-50
February	1965	1	18.0	-
March	1965	4	24.3	14-40
April	1965	4	29.8	27-33
May	1965	3	10.0	8-13
June	1965	3	9.6	9-11
	1968	4	4.3	2-6
	Total	7	6.6	2-11

Table MS-4. (continued)

Date		Number of Counts	Average Number Seen	Range
July	1965	2	6.0	5-7
	1968	2	5.0	-
	Total	4	5.5	5-7
August	1965	1	7.0	-

* Made from Green Island.

Table MS-5. POBSP Hawaiian Monk Seal ground counts on Sand Island, Kure Atoll, 1964-69.

Date of Count		Number Recorded
1964	May 29	30
	August 13	47
1965	March 27	45
	May 24	49
	July 30	26
1966	August 3	31
	August 25	25
1967	June 29	13
1968	July 4	24
	August 14	37
1969	January 18	25
	February 16	30
	April 12	34
	April 19	18
	June 12	15

Breeding Success

Table MS-6 summarizes Hawaiian Monk Seal productivity at Kure Atoll for 1964 to 1969. Only the 1964 and 1965 data are complete.

Wirtz (1968) reported that the annual reproductive rate was 15 live pups per 100 adults, that about 19 percent of the adult females bred in successive years, and that only 56 percent of the adult females had pups in either of the 1964 or 1965 seasons.

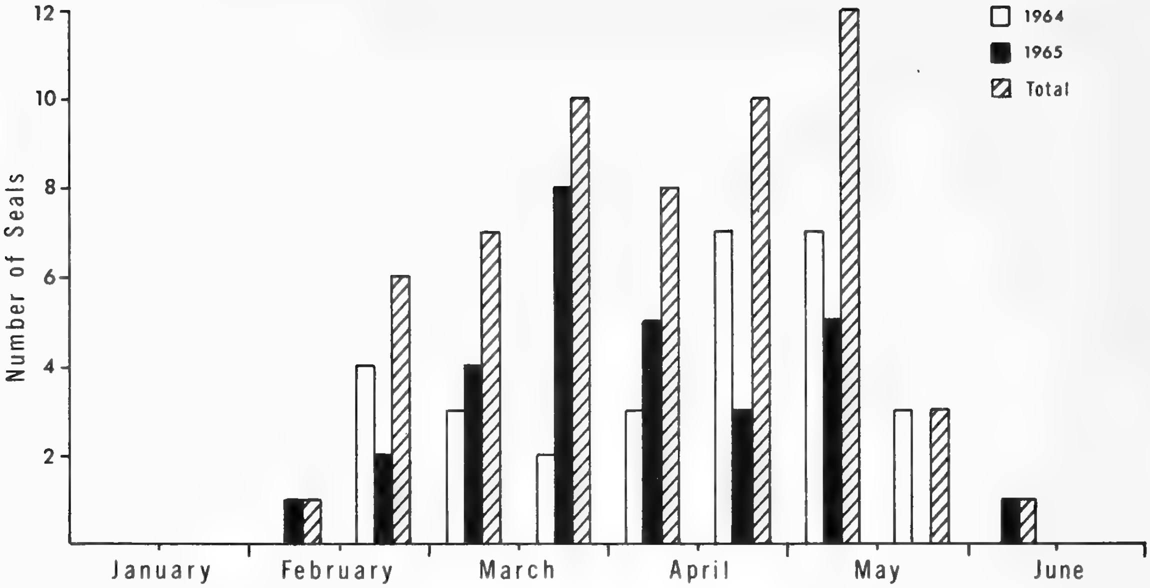

Figure MS-1. Number of Hawaiian Monk Seal pups born each semi-monthly period at Kure Atoll, 1964-65.

Table MS-6. Productivity of Hawaiian Monk Seals at Kure Atoll, 1964-69.

Year	Green Island	Sand Island	Total
1964	28	3	31
1965	29	2	31
1966*	8	-	8
1967*	13	1	14
1968*	7	5	12
1969	5**	5**	10

*Incomplete coverage. **Minimum counts.

Ecology

Hawaiian Monk Seals were found either hauled out on the beaches or swimming in the surrounding waters. At night, and sometimes during the day, they hauled out into the *Scaevola* where they slept. They were more common along the lagoon beach than the ocean beach.

Several seals that appeared to have been bitten by sharks were found. They either had circular holes in the back or greatly lacerated skin.

Movements

A subadult male tagged on 4 October 1963 was found at Midway Atoll on 4 November 1964 by Harvey Fisher. An adult male, tagged on 16 October 1963 and last noted at Kure on 27 March 1964, was found on Lisianski 12 March 1965.

DOMESTIC DOG *Canis familiaris*

In 1843 the crew of the *Parker* found a dog on Green Island that apparently had been there since the *Gledstanes* wrecked in 1837 (Whalemen's Shipping List, November 7, 1843).

During POBSP studies from 1 to 3 dogs have been kept as pets by the crew of the LORAN station. A female mixed cocker spaniel was present from 1961 to the winter of 1966-67 when she died. In early 1964 she was bred with a mongrel from Midway and produced five pups. One of these pups was kept until August 1964 when it was sent to Midway. In 1967 a new pup was brought to the atoll and during the winter of 1967-68 another arrived. Both animals remain on the atoll at this writing. Another dog was present from January to May 1969.

Generally, the dogs did not harm the wildlife on the island, although they did catch rats. However, the pup born in 1964 killed at least 7 adult Christmas Shearwaters and 7 nestling Brown Noddies; in 1968 at least 5 adult Christmas Shearwaters and a few Brown Noddy chicks were killed by the dogs. The effect of the dogs on seals is discussed in the Hawaiian Monk Seal account.

PIG *Sus scrofa*

A pig was brought to the atoll in January 1966 to be cooked at a luau, but, instead of cooking the pig, the Coast Guard kept it as a pet until August 1966 when it was sent to Midway Atoll. This animal confined most of its wanderings to the area surrounding the barracks and caused no damage to the native flora or fauna.

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